PAIN

Its Mechanisms and Neurosurgical Control

By

JAMES C. WHITE, M.D., F.A.C.S.

Chief of Neurosurgical Service, Massachusetts General Hospital
Associate Professor of Surgery, Harvard Medical School

and

WILLIAM H. SWEET, M.D., F.A.C.S.

Associate Visiting Neurosurgeon, Massachusetts General Hospital
Associate Clinical Professor of Surgery, Harvard Medical School

With assistance in the psychiatric sections of
Chapters IV and X from

STANLEY COBB, M.D.

Former Chief of Psychiatric Service, Massachusetts General Hospital
Bullard Professor of Neuropathology, Emeritus, Harvard Medical School

and

FRANCIS J. BONNER, M.D.

Assistant in Psychiatry
Massachusetts General Hospital and Harvard Medical School
Boston, Massachusetts



CHARLES C THOMAS · PUBLISHER
Springfield · Illinois · U.S.A.

CHARLES C THOMAS • PUBLISHER
BANNERSTONE HOUSE
301-327 East Lawrence Avenue, Springfield, Illinois, U S A.

Published simultaneously in the British Commonwealth of Nations by
BLACKWELL SCIENTIFIC PUBLICATIONS, LTD., OXFORD, ENGLAND

Published simultaneously in Canada by
THE RYERSON PRESS, TORONTO

Library of Congress Catalog Card Number: 54-802

Printed in the United States of America

This book is dedicated to

SIR GEOFFREY JEFFERSON

and

WILDER PENFIELD

two neurosurgeons from whom we have learned so much that we hold of value in the science and art of neurosurgery

CHARLES C THOMAS • PUBLISHER
BANNERSTONE HOUSE
301-327 East Lawrence Avenue, Springfield, Illinois, U.S.A.

Published simultaneously in the British Commonwealth of Nations by
BLACKWELL SCIENTIFIC PUBLICATIONS, LTD., OXFORD, ENGLAND

Published simultaneously in Canada by
THE RYERSON PRESS, TORONTO

Library of Congress Catalog Card Number: 54-802

Printed in the United States of America

FOREWORD

By

SIR GEOFFREY JEFFERSON, C.B.E., F.R.S., F.R.C.S., F.A.C.S. (HON.)
Emeritus Professor of Neurosurgery, University of Manchester

IT IS NOT DIFFICULT to think of the names of diseases which are unaccompanied by pain, but there are few indeed which do not cause at least discomfort which is, in a way, a diffuse or local but minor form of pain so thin that the sufferer does not use the word "pain" to describe it. On the other hand there are few affections which do not have painful phases or give rise to pain by means of secondary and local pathological alterations. In many pain is a characteristic without which the diagnosis can scarcely be made and without which the clinician feels that he has been cheated or misled. This book written by two men whose previous publications have held our attention by their close observation, by their critical analyses and by their accurate recordings is directed to those conditions in which pain has got out of hand and cannot be relieved by more moderate means than surgery in one form or another. We have long passed the stage when we believed (if many ever consistently did) that pain is a scourge directed to the purging of man's sinful existence, or a test likely to improve his character, for too often it has the reverse effect.

Sensation in general, with pain as a part buried as it were in it, remained for a long time a difficult subject for practising doctor and for physiologist. Until it had been broken down, until its components had been identified in much the same sense as that in which the chemists broke down seemingly homogeneous substances into several different ones in combination, confusion reigned. But once order had been found perhaps we got too simple an idea of what pain is, neglecting its differences in different sites, "what it feels like" here or there. How few of us have given the subject the concentrated attention that it deserves!

We should I fancy be very wrong if we thought that some modalities of sensation were in themselves of a higher order than others. Man with his relatively hairless skin and his power of describing roughly what he feels is obviously a better subject for sensory tests than is a furry animal or a fish. Man is higher in the scale because of his brain, not because of his skin. We do not know what animals feel and we are more likely to be wrong than right if we credit them with too little I mention these reflec-

PREFACE

In the preparation of a monograph on the surgical control of pain, as in reaching an understanding of the emotional factors which beset its victims, the surgeon must have the help and advice of a wise psychiatrist. We have been particularly fortunate in both these respects in having the collaboration of Dr. Stanley Cobb, former Chief of the Psychiatric Service, and his associate, Dr. Frances J. Bonner. During the six-year preparation of this manuscript they have advised us on many of our more difficult patients, they have studied all individuals before and after resort to surgery on the frontal lobes, and they have written the principal portion of the two chapters dealing with the psychological aspects of pain and its modification by psychosurgery. We feel that, without such help, any book written from a purely surgical viewpoint would lack an all important fundamental perspective.

Preparation of this manuscript was started in 1946 at the end of the war. It has proceeded slowly, thanks to the patience of Mr. Charles C Thomas, because on numerous occasions, when the work seemed nearly complete, it was held up in order to obtain further data and then submitted to repeated revisions.

The 420 patients suffering from persistent severe pain whose case histories are recorded in this volume were mostly operated upon in the 15-year period from 1935 through 1949. A number of patients with cardiac pain are included from before 1935, in fact, as far back as 1927, when the senior author was a member of the general surgical staff. Few case histories of 1944 are used, as both of us were away on military service during that year. As a general rule we have not utilized our clinical material from 1950 on, as we have wished to have a longer period of follow-up. A few patients operated upon during the last two years have been included if of special interest or needed to make up an adequate series of cases, but only when the end results have been clear cut. The need for long periods of post-operative observation was borne home forcefully to one of us after an article he wrote (Sweet, 1947). Out of three individual case reports therein related to non-fatal disorders there was recurrence of pain in two of the patients shortly after the article was published; yet both of these patients had been relieved for over a year postoperatively.

While a large proportion of this case material is made of our own patients there are also included a considerable number treated by Drs. William Jason Mixter, John S. Hodgson, Jost J. Michelsen, Hannibal Hamlin,

tions because I was myself taught under Sir Henry Head's influence at a period when pain was regarded as a low or primitive type of feeling, more suitable for lower creatures than for man. Yet one does not need to be widely informed in biology to know that a light touch can be not only a vitally important defensive attribute but also be of acquisitive use to very primitive life forms for the prehension of food. Many animals if they have neither smelled, seen, nor heard an approach move with startling suddenness at a touch. If the intruder is an enemy they will already have waited too long, but if they stayed until they felt pain they would indeed have delayed fatally.

It will not do then to regard pain as a debased sort of sensation. It can be elicited, as all the world knows, in many different ways and to have shadings and overtones which are beyond the powers of our vocabularies to describe. This may be partly because pain itself is a compound or, to change the metaphor, has a spectrum, being mixed with other sorts of feelings that are unpleasant without ranking as pain in the sufferer's mind—if he can be got to analyse his discomfort and describe it — a rare event.

However that may be, this book is concerned with pain not as a warning signal but with pain as an enemy that can be defeated. Medicinally unrelievable pain works to such a degree on man's emotions, so reduces his usefulness to himself and others, so saps his morale that we must rehabilitate him if we can An authoritative book like this on the means by which to do it is invaluable. Its virtue is that it has been written out of rich experience. This is no "scissors and paste" affair On the contrary, the writers only give their approval to such operative steps as they have themselves treated and have found to fit the case. I am happy indeed to write a few words of introduction for a work by two men whose friendship I value and whose intellectual integrity is well known to all. Their opinions will be welcomed wherever surgeons, and in fact any medical men, are faced with the difficult problems brought up by unrelievable pain. And in what country are there not such cases and their consequent conundrums?

GEOFFREY JEFFERSON

Manchester, England

TABLE OF CONTENTS

H. Thomas Ballantine, Bertram Selverstone and Reginald H. Smithwick. Others have been operated upon by our residents. We wish to express our great indebtedness to all these past and present members of the Massachusetts General Hospital staff for their kindness in giving us complete access to their records. We are also grateful to G. Hurford, Esq., house governor of the Queen Elizabeth Hospital in Birmingham, England, and to the medical services of the U. S. Navy and Veterans Administration for permission to include many of the cases reported below.

We are likewise indebted to many other individuals for assistance in the preparation of this manuscript, particularly to our secretaries, Miss *Lucy Allen, Mrs. Valerie Riddell and Mrs. Julia W. Stickley;* to Mrs. Muriel McLatchie Miller and her associates, Mrs. Edith Tagrin, Miss Wilma Riley and Mrs. Janet Desley for their excellent drawings; and to the Photographic Department of the hospital for reproducing the other figures. Drs. Ralph Hawkins and Richard G Nilges spent many hours of extra duty during their residencies in the detailed examination of patients after cordotomy and Mr. Elias C. Dow spent a summer vacation while in Tufts Medical School obtaining follow-up information on these patients.

Further acknowledgments are due to numerous medical journals and society transactions that have permitted us to utilize data which we had *previously reported in their publications In this respect we are especially* indebted to the Macmillan Company, the Association for Research in Nervous and Mental Disease, and to the editors of *Medicine, Annals of Surgery,* the *American Journal of Surgery* and *Brain.*

Last but not least, we desire particularly to thank the trustees of a certain foundation for medical research that wishes to remain anonymous. Their generous grants have defrayed the entire expense incurred in the preparation of this book.

JAMES C WHITE, M. D.
WILLIAM H. SWEET, M. D.

Massachusetts General Hospital

TABLE OF CONTENTS

PART II

Surgical Technique

PART III

Treatment of Specific Painful Conditions

Chapter *Page*

LIST OF ILLUSTRATIONS

Figure *Page*

Figure Page

LIST OF TABLES

PAIN

CHAPTER I

INTRODUCTION

"Yet there is nothing that abateth so much the strength as paine"—attributed to Ambroise Paré

"Perhaps few persons who are not physicians can realize the influence which long-continued and unendurable pain may have upon both body and mind." Thus wrote Weir Mitchell in 1872. To-day, when so much can be done to alleviate chronic pain, the majority of physicians either fail to appreciate the wisdom of this statement or are unaware of what neurosurgery has to offer when all other methods of treatment save narcotic drugs have failed. Under normal circumstances of everyday existence the sense of pain is a valuable warning of bodily injury. This is also true in many forms of acute illness, as pain calls such forcible attention to the presence of an abscessed tooth, deficient coronary circulation, an inflamed appendix, or renal calculus. In many chronic conditions, however, it serves no useful purpose of any sort. This is true primarily in cancer, where the onset of pain comes too late to warn the patient during the early, operable stage of this disease and ultimately so often becomes his chief tormentor. Pain in a number of otherwise harmless conditions such as trigeminal, post-herpetic, and amputation stump neuralgias, causalgia, Sudeck's osteoporosis, etc. is also a serious problem. Under certain circumstances pain, once started, seems to maintain itself. As Leriche has taught, it produces vasoconstriction, which in turn may redouble the pain, and thereby give rise to a vicious circle. All too often pain alone is responsible for total incapacity, if not added psychical deterioration, drug addiction, and even death by suicide. Unless narcotic addiction is too far advanced, most of these sufferers can be relieved and rehabilitated by interruption of appropriate pain pathways, so that even the victims of incurable disease can end their days in relative comfort. As far as pain is concerned there is no justification for release from life by euthanasia.

In theory, our present knowledge of anatomy should make it possible for the surgeon to relieve all varieties of intractable pain by specific interruption of afferent pathways, but this is unfortunately far from the case. Frequent failure to benefit herpetic and other neuralgias of the face other than the classical tic douloureux, certain painful phantoms following amputation, and the intensely disagreeable sensations which sometimes follow

injury of the spinal cord and peripheral nerves serves to remind us that we still have much to learn. On the other hand, the middle-aged neurosurgeon can take comfort in the thought that within the span of his practice he has learned to relieve the pain of angina pectoris and nearly all other varieties of intractable visceral disease, together with the suffering which accompanies the terminal stages of most forms of cancer. In addition, from recent war-time experience he has found a way to relieve the majority of amputation neuralgias and the burning hyperpathia of causalgia, which was described so graphically by Weir Mitchell (1872) during the War between the States and was again the cause of so much uncontrollable suffering at the period when he was gaining his medical education during the First World War.

In addition to the need for discovering an effective answer to the present unsolved problems of pain transmission, the neurosurgeon has still to educate the general practitioner concerning the advantages of early operation before the sufferer becomes addicted to narcotic drugs or develops a psychoneurotic fixation on his complaints. All too often these two factors result in the failure of a technically perfect denervation. The ordinary doctor rarely comprehends how little the sufferer has to pay in the way of risk to life or serious complication to counterbalance the incalculable recompense of freedom from pain The patient who has had a sympathectomy for visceral pain will observe no detectable changes except for the regional warmth and dryness of the skin which result from coincidental interruption of vasoconstrictor and sudomotor fibres Even after a well performed cordotomy the subject may have little if any residual disability. He will have to take care that he does not blister his foot with a new, tight shoe or burn his thermanaesthetic fingers with a cigarette. We have had among our patients a waiter employed at one of the Boston hotels after bilateral cordotomy for tabetic crises and a golfer who can still play an 18-hole course in under 80 after a unilateral section of his spinothalamic tract for post-amputation neuralgia. A woman roller-skater in vaudeville who has had the tract cut at the second cervical vertebra has been able to skate again.

As a general rule it is advisable to undertake neurosurgical intervention for the relief of intractable chronic pain before the individual becomes neurotically introspective over his suffering or addicted to opiates. If life-expectancy is limited to as short a period as two months or less, morphine and its derivatives can often keep the patient in relative comfort. On the other hand, if he is destined to live for a longer period it is unlikely that he can get along with increasing narcotic dosage without suffering the unpleasant side-effects of the drug and developing a craving for it which leads inevitably to psychical deterioration.

In general we advise recourse to surgery for relief of pain as soon as the cancer patient with an even moderate life-expectancy begins to require medication stronger than codeine. For the sufferer from chronic intractable visceral disease, we believe that surgical intervention is justified in reasonable operative risks just as soon as it has been established that conservative treatment cannot salvage him from serious incapacity and worry over his pain. With the more benign neuralgias it is incumbent on the patient to make his own decision. He alone knows the intensity of his suffering. The surgeon should tell such a patient frankly just what he has to face in the way of risk to life, serious complications, or chance of failure in exchange for relief. The decision for operation must be made by the patient himself and it can be undertaken successfully only with his complete cooperation.

The pioneer efforts of the surgeon to relieve unbearable pain date back to a report by Ambroise Paré (1598). In the course of bleeding King Charles IX for the smallpox Antoine Portail's lancet had injured a superficial nerve with the production of intense pain and contraction of the arm. After more than three months of suffering the king happily recovered, but Paré stated in his commentary that, had other remedies not been successful, he was prepared to use boiling oil in the wound or to have severed the nerve completely. From present-day experience we may consider the king's spontaneous remission to have been fortunate. Maréchal, surgeon to Louis XIV, inaugurated neurotomies for tic douloureux toward the end of the seventeenth century.

Modern neurosurgical procedures for pain may be considered as beginning with the work of the great British surgeon Victor Horsley (see Horsley, Taylor, and Colman, 1891) for the relief of trigeminal neuralgia by Gasserian neurectomy, which was continued by Hartley (1892), followed by Krause (1893*A*) in Germany, and finally perfected by Frazier in Philadelphia from 1901 to 1915 (see Frazier, 1928*A*). Harvey Cushing's efforts were so concentrated in the field of neoplastic surgery that beyond his reports of total extirpation of the Gasserian ganglion (1900, 1920*B*) he contributed little to the surgery of pain. The first spinal rhizotomies are accredited to Abbe (1911). In 1905 Spiller of Philadelphia discovered that pain is conducted in the anterolateral columns of the spinal cord and urged Martin to carry out the first successful cordotomy (Spiller and Martin, 1912). Otfried Foerster of Breslau made the first thorough study of the pathways of pain conduction and mapped the spinal dermatomes in man (1933).

Credit for the conception of the great potentialities of sympathectomy goes to François-Franck (1899), professor of physiology in Paris at the end of the last century. His ideas of surgical relief in intractable angina pectoris were put to the first successful test by the Rumanian Theodore

injury of the spinal cord and peripheral nerves serves to remind us that v still have much to learn. On the other hand, the middle-aged neurosurge can take comfort in the thought that within the span of his practice he h learned to relieve the pain of angina pectoris and nearly all other varieti of intractable visceral disease, together with the suffering which accor panies the terminal stages of most forms of cancer. In addition, from rece war-time experience he has found a way to relieve the majority of amp tation neuralgias and the burning hyperpathia of causalgia, which w described so graphically by Weir Mitchell (1872) during the War betwe the States and was again the cause of so much uncontrollable suffering the period when he was gaining his medical education during the Fir World War

In addition to the need for discovering an effective answer to the prese unsolved problems of pain transmission, the neurosurgeon has still to ed cate the general practitioner concerning the advantages of early operati before the sufferer becomes addicted to narcotic drugs or develops a psych neurotic fixation on his complaints. All too often these two factors res in the failure of a technically perfect denervation. The ordinary doct rarely comprehends how little the sufferer has to pay in the way of ri to life or serious complication to counterbalance the incalculable recor pense of freedom from pain. The patient who has had a sympathecton for visceral pain will observe no detectable changes except for the region warmth and dryness of the skin which result from coincidental interruptic of vasoconstrictor and sudomotor fibres. Even after a well performe cordotomy the subject may have little if any residual disability He w have to take care that he does not blister his foot with a new, tight sh or burn his thermanaesthetic fingers with a cigarette We have had amor our patients a waiter employed at one of the Boston hotels after bilater cordotomy for tabetic crises and a golfer who can still play an 18-hole cour in under 80 after a unilateral section of his spinothalamic tract for pos amputation neuralgia A woman roller-skater in vaudeville who has ha the tract cut at the second cervical vertebra has been able to skate again.

As a general rule it is advisable to undertake neurosurgical interventic for the relief of intractable chronic pain before the individual becom neurotically introspective over his suffering or addicted to opiates. If lif expectancy is limited to as short a period as two months or less, morphir and its derivatives can often keep the patient in relative comfort. On th other hand, if he is destined to live for a longer period it is unlikely that h can get along with increasing narcotic dosage without suffering the u pleasant side-effects of the drug and developing a craving for it whic leads inevitably to psychical deterioration.

PART I
FUNDAMENTAL ASPECTS

Jonnesco in 1916 (1920, 1923). The early appreciation and demonstration of the role of vasoconstriction in painful conditions of the extremities originated unquestionably with Leriche (1913).

Fulton and Jacobsen's findings (1935) that chimpanzees deprived of their frontal lobes are no longer concerned over the ordinary frustrations to which they can be exposed by the human investigator and Egas Moniz' (1936) brilliant adaptation of this observation to the release of psychotic individuals from anxiety and introspection have opened a way to relief from suffering in otherwise intractable painful states. Frontal leucotomy, although not strictly speaking a specific operation for the relief of pain, has become an invaluable method for controlling suffering from the varieties of intolerable discomfort for which no other solution is known. Leucotomy will also bring relief to the victims of hopeless disease. The price that must be paid in the loss of finer qualities of the patient's personality and mental deterioration makes this an operation of last resort which can never justifiably be undertaken so long as any specific procedure is available for relief. Whether newer modifications such as the various corticectomies and cortical undercuttings can be counted on to give consistent satisfactory relief still remains to be ascertained.

The first book to our knowledge on the surgery of pain was written by Létiévant (1873) and was primarily concerned with neurectomies for neuralgias of the face and extremities. Following in his wake there has been a series of outstanding and thought-producing volumes on this subject. Mention of those which have been of the greatest help to us includes Fulton's textbook of neurophysiology (1949), the special monographs on pain by Mitchell (1864, 1872), Foerster (1927*A*), Lewis (1942), Livingston (1943), Leriche (1949), and the collection of papers from the 1942 symposium on pain of the Association for Research in Nervous and Mental Disease (1943). These everyone who is interested in this problem should read. We wish to take this occasion to acknowledge our indebtedness to these sources, from which we have quoted freely in the following pages.

This book is concerned with the problems of neurosurgical relief of pain for which there is no direct medical or surgical cure. The field has expanded rapidly during the past twenty-five years. Statistical data on which our account is based extend over this period and are derived from the case histories of the Massachusetts General Hospital, the Queen Elizabeth Hospital in Birmingham, England, the New England Center Hospital, Boston, the U. S. Naval Hospitals at Chelsea, Massachusetts, and St. Albans, New York, and the Cushing Veterans Administration Hospital at Framingham, Massachusetts.

CHAPTER II

END ORGANS, AFFERENT TRACTS, AND CENTRAL STATIONS CONCERNED WITH THE TRANSMISSION AND APPRECIATION OF PAIN

A. END ORGANS OF PAIN

ERASMUS DARWIN (1794, pp. 121 and 125) considered pain to be the consequence of any excessive stimulation and to result when sensations of heat, touch, sight, sound, taste or smell were exaggerated. The first critical studies in the field of cutaneous pain brought the concept of specific points especially receptive to painful stimuli described in man by Goldscheider (1885). Conversely he found that a fine needle could be stuck painlessly into many points of the human skin. This basic observation, since often confirmed by way of parlour entertaining, was extended by von Frey (1894-1929) in his exhaustive studies with calibrated hairs and thorns. He insisted on a distinction between the spots in which the sole threshold response to a point was a sense of pain, and those other spots in which it was a sense of pressure. He was also able, he thought, to correlate the distribution of cold, warm, and pressure spots in the skin with the respective frequency of Krause's corpuscles for cold, Ruffini's endings for warmth, and with the special nerve endings around the hair roots and Meissner's corpuscles for touch (Fig. 1). Bazett *et al.* (1932) considered that they confirmed this in man with respect to the cold and warm spots in a thorough critical analysis of sensation on the human prepuce followed by histologic study of this tissue removed at circumcision. Regarding the certainty of such precise correlation, however, we quote Woollard (1935), "in the maze of descriptive anatomy of nerve endings it is difficult to be certain about the identification of one description with another."

The skin shows, in addition to the complex endings, multitudinous branching, unmyelinated, finely beaded plexiform endings (Fig. 1) which have been thought to correlate with the multiplicity of pain points—as many as 200 per sq. cm. (Strughold, 1924). Such endings are found at all dermal and epidermal levels. In connection with this fact Woollard (1935), testing sensation over a small area of his own thigh after the removal of each of a succession of thin slices of skin, found pain to be the most superficial as well as the most extensive in depth of the modalities

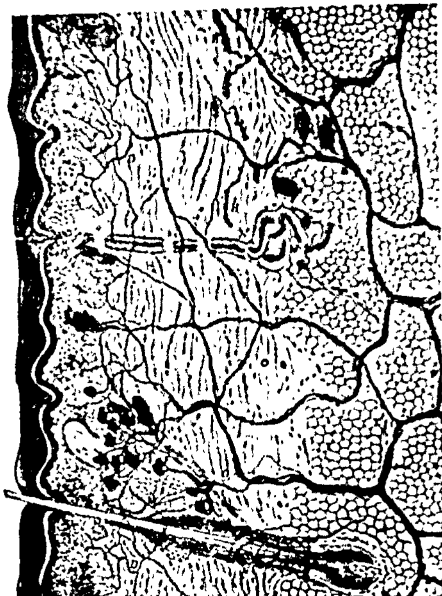


Fig. 1. Composite diagram showing the innervation of the human skin.

A. Merkel's disc, subserving touch. B Free endings, subserving pain, scattered throughout deeper layers of epidermis. C. Meissner's corpuscles, subserving touch. D. Nerve fibres, subserving pain. E. Krause's end bulbs, subserving cold. F. Nerve endings subserving warmth (sometimes called Ruffini's endings). G. Nerve fibres and endings on hair follicles, subserving touch. H. Ruffini's endings, subserving pressure. I. Sympathetic nerve fibres innervating a sweat gland. J. Pacinian corpuscles subserving pressure. K. Golgi-Mazzoni endings, subserving pressure. L. Nerve tranks containing thick and thin fibres. M. Sebaceous gland. N. Sweat gland. O. Sympathetic nerve fibres supplying erector pili muscle

Drawing composed from methylene-blue and reduced silver preparations. The functional interpretations summarized above are based upon observations by Woollard, Weddell, and Harpman, *J. Anat.*, 1940. Figure reproduced by permission of the editor.

We do not agree that the free endings necessarily subserve only pain sensation.

tested. He also found histologically a plexus of finely beaded nerve fibres among the epithelial cells in one region of his own epidermis which was especially sensitive to the point of a needle. Woollard, Weddell and Harpman (1940) saw only such nerve terminals in human skin taken from just distal to an ulcer made with solid carbon dioxide. The biopsy was taken eight days later when pain was the only sensation elicitable in this area. Foerster and Boeke (see Foerster, 1927A, p. 16) however, following division of nerves in several people were unable to find any free intraepithelial nerve endings in sections of skin taken from areas in which pain was the only type of sensation found. Waterston (1933A), also in disagreement with Woollard's concept, believed that the nerves of the normal epidermis mediate touch alone, since he was able to slice this tissue painlessly from himself with a razor. He demonstrated in the shavings of this skin nerve fibres terminating in loops and fine arborescent figures. Perusal of Woollard's (1935) careful account also discloses that when the first slice of his skin 5 x 22 mm. in size was cut, he felt pain only at four previously ascertained "pain spots" The sense of touch which he presumably felt during the remainder of the slicing process may well have been mediated, at least in part, by the other fine nerve fibres in the epidermis. From the data presented in the literature to the present it appears to us that the epidermis as well as the corium contains structures giving rise to both touch and pain.

Beginning in the last century and continuing through the first quarter of this one von Frey (1922) and Goldscheider (1920) engaged in a continuous controversy in the literature as to whether or not there are separate nerve endings in the skin which mediate the sense of pain. Their debate serves to illustrate one of the major difficulties in the field, to wit, that each observer relies on his own personal sensations to stimuli. Perhaps the most striking discrepancy between statements in the literature and what we should consider to be common experience is the allegation (von Frey, 1895; Rivers and Head, 1908, p. 444; Lewis, 1942, p. 2) that the surface of the glans penis is capable of responding to stimuli only with a sense of cold or of diffuse, poorly localized pain. While this may be true under conditions of routine laboratory testing in uncircumcised subjects, we regard it as manifestly absurd under many other circumstances. After reviewing some hundreds of the pages of argument on cutaneous sensation and repeating some of the studies with calibrated hairs and thorns, it appears to us that the basic original observation of Goldscheider (1885) is inescapable—that the threshold response to minimal stimulation with a minute pointed needle is one of touch at the great majority of all spots on the skin of the body. We have found this to be the case even in areas specifically recommended by von Frey (1922) for eliciting pain in prefer-

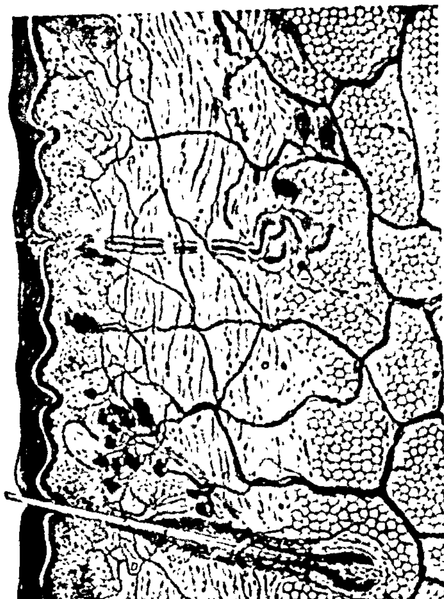


Fig. 1. Composite diagram showing the innervation of the human skin.

A. Merkel's disc, subserving touch. B. Free endings, subserving pain, scattered throughout deeper layers of epidermis. C. Meissner's corpuscles, subserving touch. D. Nerve fibres, subserving pain. E. Krause's end bulbs, subserving cold. F. Nerve endings subserving warmth (sometimes called Ruffini's endings). G. Nerve fibres and endings on hair follicles, subserving touch. H. Ruffini's endings, subserving pressure. I. Sympathetic nerve fibres innervating a sweat gland. J. Pacinian corpuscles subserving pressure. K. Golgi-Mazzoni endings, subserving pressure. L. Nerve tranks containing thick and thin fibres. M. Sebaceous gland. N. Sweat gland. O. Sympathetic nerve fibres supplying erector pili muscle.

Drawing composed from methylene-blue and reduced silver preparations. The functional interpretations summarized above are based upon observations by Woollard, Weddell, and Harpman, *J. Anat.*, 1940. Figure reproduced by permission of the editor.

We do not agree that the free endings necessarily subserve only pain sensation.

ence to touch, such as the skin over the eyelids, the biceps brachii and the clavicle. Hence, the sense of touch on the skin being even more nearly ubiquitous than that of pain, we regard it as possible or even likely that appropriate stimulus of many, if not all, of the widely disseminated, unmyelinated endings in the skin evokes a sense of touch when normal innervation is present. Whether the same endings or different but histologically similar ones are concerned with the diffuse capacity to appreciate pain remains to be demonstrated. Kadanoff (1928) described in silver preparations of epithelium from a variety of sites two kinds of nerve fibres entering the epidermis: (1) a thicker fibre which gives off lateral branches and (2) a thinner one which remains unbranched. He suggests that these differences may have a functional significance. Woollard (1935), on the other hand, from his methylene blue preparations in man states that he could not distinguish these two types of fibres.

Investigation of those surfaces of the body supplied only by fine unmyelinated nerve endings would appear to be decisive in ascertaining the sensory function of these particular endings. It is well established that the cornea contains only such terminations; these ramify both beneath and within the epithelial layer (Dogiel, 1890; Cajal, 1909; Boeke, 1935, and many others). The nasal mucosa (Cajal, 1909; Kadanoff, 1927) and the tympanic membrane (Wilson, 1911) are thought as well to contain only endings of this type. Von Frey (1896), Lewis (1942) and others have stated that from the cornea one may elicit pain but not touch or pressure. Von Frey (1929) and Lewis made the same statement regarding the sensation from the nasal mucosa above the vestibule. The dentine of the normal human tooth also gives rise to no sensation other than pain (von Frey, 1895, Brashear, 1936), and Lewinsky and Stewart (1936) report that only free nerve terminals are found there. Goldscheider, however, finds the threshold sensation on the cornea to be one of touch or pressure Nafe and Wagoner (1937) agree and cite five other investigators who concur with them We are under the impression that our own nasal mucosas above the vestibules are capable on stimulus with a calibrated hair of appreciating touch with no disagreeable associated quality whatsoever. We have, as well, seen many patients in the older age group without specific trigeminal or cerebral lesions who will allow a pinhead to rest on the cornea and deny pain, yet feel the touch of the object. This is a striking and frequent observation, yet in such contrast to our own reaction to contact of a foreign body with the cornea that, in earlier days when we were novices at neurological examination, we were led to the erroneous inference of a focal lesion in the trigeminal pathways on encountering a patient who ignored such a stimulus.

In patients following bulbar trigeminal tractotomy the cornea becomes

completely analgesic to pain even on high voltage electrical stimulation—yet retains its sensitivity to touch (see Chap. XIV). We have also noted that the tympanic membrane loses its capacity to feel pain after bulbar trigeminal tractotomy, but still retains its sense of touch. We are convinced that in these abnormal conditions following tractotomy, central pathways persist by means of which stimuli arising from naked unmyelinated endings are interpreted as touch. It appears then that the central connections of any given nerve fibre have a decisive role to play and that, in consequence of variations therein, the degree to which naked nerve endings from a given area subserve touch as well as pain may vary. Further, changes in excitability of the receptive and integrative centres in the central nervous system may determine whether at any moment a stimulus from a given point be interpreted as touch or as pain. An apathetic patient with an intracranial tumour may at times ignore the painful quality of a pinprick, describing it only as touch. Some minutes later he may find that same stimulus in the same area acutely painful. The brilliant investigators responsible for much of the work on superficial sensibility have drawn conclusions from their own body surfaces and alert penetrating minds. We need, as well, to analyze observations of those of average mentality and of those with disease in order to obtain a broader view of the behaviour of the nervous system.

In addition to the fine, naked nerve endings in the skin, there is often a similar type, a so-called "accessory fibre" (Remak fibre, Timofeevew fibre) associated with the encapsulated elaborate sensory endings of Meissner, Ruffini and Krause. Many of the deep receptors, the Vater-Pacinian corpuscles, the neuro-tendinous endings of Golgi and others may have such a fine fibre as well (Fig. 2). The function of these is perhaps related to another unresolved controversy, i. e., does excessive stimulation of the acknowledged specific receptors for touch, coolness and warmth cause pain as well? With respect to touch, if we hold the hairs of our forearms just close enough to feel a rapidly vibrating machine there is no sensation which is at all painful. One can thus in a few minutes in man confirm conclusively what Adrian, Cattell and Hoagland (1931) and Adrian (1931) decided with respect to frogs and cats, that is, that tactile receptors do not give rise to pain regardless of how high the frequency of stimulation. Their experiments have shown that the sensory end organs so stimulated were evoking impulses near the maximal frequency in their connected nerve fibres, which were then, even at presumed peak performance, causing no pain.

While it is possible to confine a stimulus to hairs and their special sensory end organs, no such direct experiment appears to be feasible in the case of the special organs of temperature sense. Trotter and Davies (1909)

regarded the sensation of "hot" as a combined experience of warmth and pain, and similarly thought "cold" combined an appreciation of coolness and pain. With increasing thermal difference the sense of temperature disappears and pain alone remains. One might assume that this pain sensation arises from activation of the fine nerve endings throughout the area



Fig 2 Photomicrograph showing a Vater-Pacini corpuscle in the deep fascia of the human leg The arrow points to the "accessory" fibre Methylene blue preparation

From Weddell and Harpman, *J Neurol & Psychiat*, 1940, by permission of the editor.

affected by the stimulus. At this point the cornea comes in again as a handy preparation. On exposure to heat, if this assumption is correct, the fine corneal fibres which have no thermal receptors should give rise only to a sensation of pain, if they are capable of responding to such a stimulus. Nafe and Wagoner (1937), however, found that excessive heat to this structure caused no sensation either of heat or of pain. Consequently, since the general network of fine, unmyelinated endings seems inactive during this stimulus, it may be that the specific fine fibres accessory to the thermal end organs are activated by extremes of temperature and give rise to the accompanying pain. Woollard (1937), in support of this hypothesis, has illustrated an "accessory" fibre derived from the subepidermal pain plexus terminating at a Krause end bulb. Lavrenko and Kolossov (see Lavrenko, 1938) have shown that these accessory fibres are not associated with the sympathetic innervation. No other function than that of appreciation of pain under special circumstances has been suggested for these accessory fibres It is not so clear, however, that this hypothesis explains the function of these fibres with respect to the corpuscles of Meissner, in which type of encapsulated sensory ending they appear to be well developed (Ruffini, Dogiel and Crevatin cited by Foerster, 1927A, p. 17, Weddell and Harpman, 1940).

These corpuscles have been associated with reasonable certainty with the sense of touch, yet as we saw earlier, stimulation of the hair follicles by an excitation causing maximal rate of impulse production adds no sense of pain to that of touch.

Much less has been done to associate types of pain and discomfort arising from deeper somatic or visceral stimulation with specific types of sensory receptors. The same type of free nerve ending often associated with pain in the skin is also seen in a number of serous membranes (Dogiel, 1902; Timofeyew, 1902; Michailow, 1908, Kadanoff, 1924), subserous coat of gut (Hill, 1927), intermuscular connective tissue (Hinsey, 1930), choroid plexus (Stöhr, 1928), tendon surface and substances, deep fascia and periosteum (Weddell and Harpman, 1940), and the adventitia of blood vessels (Woollard, 1926; Hinsey, 1928; Woollard, Weddell and Harpman, 1940). Pain is readily evoked in all of these structures. Dogiel (1898) found a much better developed plexus of nerve fibres in the adventitia and muscularis in the arteries than in the veins. In the aorta and pulmonary arteries similar presumed sensory endings occur in the intima as well. These findings are in accord with the severe pain usually felt on arterial puncture in man as contrasted with the customary absence of pain when a vein is penetrated (Bazett and McGlone, 1928; Waterston, 1933A). Landis (1930), in his studies on capillary blood pressure in man, noted that pain occurred when his micro-pipette penetrated these tiny vessels.

The sensitivity of the internal organs and the types of stimuli which evoke visceral pain are discussed in the following chapter. Under appropriate conditions all of these structures are sensitive to pain. The actual difference in sensory threshold of viscera and other deep structures, on the one hand, and the integument, on the other, appears to be related in a quantitative manner to the concentration of fine sensory axones

B. TERMINAL SENSORY PLEXUSES

Each individual nerve fibre ramifying in the subcutaneous tissue and skin appears to be entirely distinct from its neighbour, according to both Woollard and Weddell. The nerve plexuses in the region are not a syncytium, even though the nerve fibre subserving pain from one dorsal root ganglion cell supplies a considerable area of skin.

The question has arisen as to how such a disposition is compatible with "spot" sensation and localization. As early as the last century Bethe (1894) had given what we now consider to be the correct answer. He found that relatively few stem nerve fibres, each dividing into many branches, innervate all of the sensory end organs of the frog's tongue. Each end organ was supplied by at least two branches, which, however, never came from

the same stem fibre. Bethe thus envisaged a mechanism for sensory localization without overloading the main conduction pathways with individual nerve fibres. Boring (1916), on the basis of a penetrating analysis of his own sensation after division of a cutaneous nerve, explained the facts he observed by the assumption "that single sensory spots are innervated by more than one nerve fibre, that the multiple innervation is projected on the central nervous system." Thus a tiny area of skin might give rise to a pattern of excitation differing sufficiently from its neighbours to permit of localization and two-point discrimination. The raised threshold observed after section of one of the sensory branches supplying the area to be tested would also be explained. This hypothesis has been confirmed from several angles. Weddell (1941 A and B) has provided an actual histologic demonstration that each sensory "touch" spot on the skin is innervated by endings from several different nerves. Thus while each stem fibre is distributed to as many as three hundred hair follicles on a rabbit's ear, each of these follicles is supplied by branches from two to seven stem fibres. With respect to pain he found the terminal net of a single fibre on the dorsum of the hand in man to be about 7.5 mm. in diameter. The threshold of two point discrimination for pain in this region is about the same.

The concept of multiple innervation of sensory spots has been extended with respect to pain, and the functional field of individual nerve fibres has been analyzed brilliantly by Tower (1943) working in the corneo-conjunctival region of the cat with a preparation containing one to three fibres. This is one locus in which it is perhaps reasonable to assume that a stimulus well above threshold evokes pain uncomplicated by other sensations in the normal animal The uniform histological appearance of the nerve endings and the accounts of sensation obtained from man form the basis for this assumption. An oscilloscopic recording of the action potentials from a preparation of a few fibres was made in the course of stimulation of the cornea with hairs, needles or glass rods. One isolated nerve fibre yielding fairly large impulses was found to fan out over roughly one fourth of the cornea and some of the adjacent sclera This fibre did not supply every part of this large area, but in a two fibre preparation both of these surviving fibres might do so When many fibres remained active their fields overlapped inextricably. It was striking that responses differed from different parts of the field of the same fibre. Tower found that "low threshold and slow adaptation characterized the central region of the terminal fields of individual fibres, and rapid adaptation more than high threshold, the peripheral parts." A strong stimulus near the centre of the field of the fibre might push the frequency of the response to about 500 per second or about the limit permitted by the refractory properties of the fibre. Tower

demonstrated not only the interlocking of the territories of nerve fibres but also that the frequency, duration and rate of adaptation of impulses within the field of one fibre were determined by site as well as by intensity of stimulus. Thus other possible variables in the data presented centrally increase the likelihood of precise spacial discrimination peripherally. By cerebral analysis of signals from fibres excited minimally, which encircle other active fibres excited more vigorously, localization may be achieved. The frequency of discharge in the fibre or fibres most excited would still indicate the intensity of the stimulus.

C. SENSORY NERVE FIBRES

As one's attention progresses from the terminal fields of nerve fibres to the fibres themselves in the peripheral nerve trunks, one finds that here also strenuous efforts have been made to correlate anatomical characteristics with function. From the evidence amassed by Gasser and collaborators (see summary by Gasser, 1946) regarding the physiological properties of nerve fibres, they were able to show that the velocity of conduction in "A" fibres varied directly with the diameter of the axone.*

The largest A fibres (around 16-20μ in diameter) transmit impulses at 90-115 metres per second, whereas a velocity of but 10 metres per second is found in the smallest myelinated fibres, 2-4μ in diameter In contrast to this rapid transmission the unmedullated fibres in sensory nerves, 2μ in diameter or less, which have been called C fibres, conduct at from 0.6 to 2 metres per second. Each component of the action potential of a C fibre is of much longer duration than the corresponding part of the action potential of an A fibre.

Ingenious efforts have been made to determine which of these sensory fibres is associated with pain, and it appears that both the smaller medullated fibres of from 2-5μ in diameter (the delta-epsilon group) and the unmyelinated C fibres may be concerned. The larger of the presumed pain fibres transmit at up to 20 metres per second, a sufficient contrast to the slow rate of the C fibres to permit perception of a "fast pain" and a "slow pain." A double pain response to a single painful stimulus has been noted by numerous observers; the first flash of pain comes on almost at once, the second after a detectable latent period. Gasser finds that touching the

*Their classification of nerve fibres is based on the duration and configuration of the three components of the action potentials in the fibres; these include the initial negative spike, then the negative and finally the positive after-potentials. Their "A" fibres include all the medullated fibres in somatic nerves and some in the visceral nerves as well The "A" fibres have been subdivided into five groups designated in order of diminishing diameter by the letters alpha through epsilon.

skin at the base of the finger nail to a hot light bulb is a gesture which gives him two such distinct bursts of pain. Zotterman (1933) was the first to suggest that the primary flash of pain was conducted by the faster delta group of A fibres, whereas the delayed second pain would be conducted over C fibres. Many investigators have been able to detect in themselves a clear-cut interval between the two bursts of pain, an observation which fits in well with the substantial divergence between the slowest speed of the myelinated and the fastest speed of unmyelinated fibres. Presumptive anatomical variations of pain pathways traversing the posterior horn of the spinal grey matter have also been adduced to account for fast and slow pain (see p 37).

The correlations between fibre size and modality of sensation are, however, not as good as one might hope. All conclusions are based on the dubious inference that sensations of human observers under given experimental conditions are susceptible of direct correlation with action potentials recorded from the nerves of animals under similar conditions. On the basis of studies involving cocainization or asphyxia of nerve trunks, it is thought that (1) larger medullated fibres than those in the delta group may also carry pain impulses; (2) the delta A fibres transmit touch and temperature impulses as well as those for pain; and (3) the C fibres transmit "temperature" impulses in addition to pain. Hence it would appear that impulses for each type of sensation are distributed widely throughout many of the fibre sizes. Gasser (1943 and 1946) has presented a superb summary of the whole problem.

The action potentials in most of the medullated fibres of visceral nerves differ materially from those in the foregoing two groups; so much so that they have been placed in a separate category and called B fibres. Usually a single elevation is present, with no visible negative after potential, but we know of no evidence as to what part if any the pain fibres play in this deflection. Possibly this peculiar action potential is associated with the fundamentally different type of stimulus effective in causing visceral sensation

D. SENSORY NERVES

In any given peripheral nerve in man the presence of fibres normally conducting pain is ascertainable by exposing the nerve under local anaesthesia and stimulating it. Foerster (1927A, p. 21) found that whether the stimulus is mechanical, thermal or electrical the response is always one of unpleasant paraesthesia or pain. The evoking of pain in this fashion does not necessarily mean that the fibres stimulated conduct impulses giving rise to pain in the intact individual under normal or diseased states

(see p. 45 on stimulation of the posterior columns of the spinal cord). Conversely we have noted that pain does not invariably ensue upon the mechanical stimulus of a needle in the mandibular branch of the trigeminal nerve or upon the injection therein of 95 per cent alcohol (Sweet, 1950). The location of a cutaneous nerve and the area of its principal supply may be determined readily by moving over the skin an electrode passing a faradic current. When the nerve is reached a fluttering sensation is felt in the distal part of the area supplied by that nerve and at higher current pain is noted, as proven by Trotter and Davies (1909) when they divided such nerves in themselves and checked the area of supply. Foerster (1927A, p. 26) has also stimulated in man the central ends of nerves passing to muscles and caused severe pain, thereby demonstrating that the nerves to muscles probably have an afferent component concerned with pain as well as the substantial afferent component related to proprioceptive and reflex functions (Sherrington, 1894A). Fibres conducting pain have also been demonstrated in many visceral nerves stimulated under appropriate conditions in man (see p. 82).

The area of total sensory supply of any peripheral nerve is widely overlapped by that of adjoining nerves, just as is the case for the fields of individual fibres in the same nerve. The cutaneous "autonomous" zone, the area of skin supplied by no other adjoining nerve, may be minute or nonexistent, varying greatly from person to person. The extent of this area is demonstrable by procaine block or division of the nerve in question. The much larger total or maximal zone is shown only by anaesthetic block of all of the nerves surrounding the one to be studied (Highet, 1942; Foerster, 1927A, p. 23; Pollock, 1919). Likewise the autonomous zone of deep tissues supplied exclusively by any one major peripheral nerve is small. Less extensive data are at hand on this score, but Foerster (1927A, p. 27) noted, for example, that after division of the ulnar nerve only the periosteum of the fifth finger was analgesic, after interruption of the median nerve periosteal analgesia was confined to the last two phalanges of the second and third fingers. Hence if one is to attempt to eliminate pain in a given small area by peripheral neurectomy it is often necessary to divide two or more major peripheral nerve trunks.

The precise character and significance of the sensory loss following section of a cutaneous nerve has been the subject of extended dispute. We consider it to have been well described in the painstaking studies of Trotter and Davies (1909) on themselves. They followed the changes in sensation in each instance and for many months after deliberate division of each of seven cutaneous nerves in their upper and lower limbs. Using calibrated points and hairs they found that "the changes consequent upon depriving a piece of skin of its nerve supply are distributed in a central area of absolute

loss, surrounded by a zone of much less loss which is slight toward the periphery and deepens toward the centre." Further they found that the "defect of sensibility to pain is precisely similar in character and distribution to the defects in sensibility to cold, to heat and to touch." Their observations were thorough and well recorded, and in most respects have withstood the test of experiment by others—Boring (1916), Lanier, Carney and Wilson (1935) and Lewis (1942, p. 16), as well as the critical analysis of Cobb (1919) and Walshe (1942). Examinations of sensation following division of a sensory nerve are complicated by the presence shortly after the operation of an early hyperalgesia peripheral to the anaesthetic zone and a later, more extensive hyperalgesia during a phase of regeneration. However, the presence of this phenomenon and that of remote reference of pain from the spot stimulated do not vitiate the fundamental conclusions above

Figure 3, taken from Boring's extraordinarily careful study on himself, illustrates the close correspondence between the loss to pin and that to touch. He used the same type of instrument throughout the testing, capping it with a needle to test pain and with a hair for touch. Emphasis is placed upon this because the use of methods of dissimilar precision for testing different modalities of sensation in the same person has given rise to statements that the zones of loss of one modality are consistently and significantly greater than those of another. For example, it has been contended that in a peripheral nerve lesion, the area in which sense of touch is lost is greater than that in which pain to pin-prick is absent. Boring finds that this may be true if a punctiform stimulus is used for pain and what he calls an areal stimulus, such as a camel's hair brush, is used for touch. Such a tactic is, of course, usual in clinical examination. The converse, i.e., loss to pin greater than loss to touch, is said to be true in a lesion of adjoining posterior roots (Head and Sherren, 1905, Foerster, 1933). Studies as intensive as those of Boring will have to be performed before such statements can be given the fullest credence. If they should prove to be true an adequate anatomical explanation will then have to be sought.

The nerves concerned with the distribution of pain in the deeper tissues have not been as fully worked out as those from the skin, but it has long been known that the deep branches of a nerve may supply a dissimilar or even remote area from that supplied by its superficial branches. For example, the skin of the neck is supplied by the third, fourth and fifth cervical nerves which also convey pain from the dome of the diaphragm. Inman and Saunders (1944) have attempted a systematic presentation, Figure 4, to show the nerve supply of superficial and deep muscles and the skeleton, and have coined the term "sclerotome" for the zone of deep tissues innervated from a given spinal segment. (Compare these figures with that

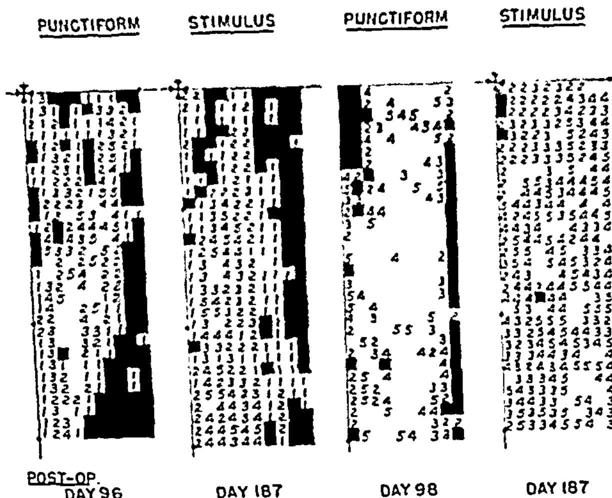


Fig. 3. Quantitative sensory testing following cutaneous neurotomy in man.

The figures illustrate the results of testing a precisely marked area 2 cm. wide by 6 cm long *within* the originally denervated zone of the subject's forearm. Many more tests were carried out than those on the stated days after the division of the cutaneous nerve. The pressure (touch) stimulus was applied via a hair of radius of 0.100 mm., the pain via a needle point. Increase *in intensity of stimulus* compressed a spring, alongside which was a scale calibrated in grams. The numbers in the illustrations show approximate thresholds in grams. Blank areas indicate thresholds of 6 gm. or more, solid black areas, thresholds of 1.5 gm or less, i.e., essentially normal threshold. In the particular pairs of illustrations selected here for comparison, the loss of pain seems slightly more marked than that of pressure (touch). However, on other days this was reversed, so that the recovery of appreciation of pain and pressure (touch) was at essentially equal rates.

From Boring: *Quart. J. Exper. Physiol.*, 1916, by permission of the editor

from Foerster, Figure 6, for dermatomes). Their brief publication gives the reader an inadequate basis for checking the accuracy of the data on which the diagrams are based, but their effort represents a major step in a needed direction. There is such disagreement between gross anatomists as to the nerve supply of a given muscle (Foerster, 1929, p. 947 and p. 966) that construction of a chart from such data leaves much to be desired.

loss, surrounded by a zone of much less loss which is slight toward the periphery and deepens toward the centre." Further they found that the "defect of sensibility to pain is precisely similar in character and distribution to the defects in sensibility to cold, to heat and to touch." Their observations were thorough and well recorded, and in most respects have withstood the test of experiment by others—Boring (1916), Lanier, Carney and Wilson (1935) and Lewis (1942, p. 16), as well as the critical analysis of Cobb (1919) and Walshe (1942). Examinations of sensation following division of a sensory nerve are complicated by the presence shortly after the operation of an early hyperalgesia peripheral to the anaesthetic zone and a later, more extensive hyperalgesia during a phase of regeneration. However, the presence of this phenomenon and that of remote reference of pain from the spot stimulated do not vitiate the fundamental conclusions above.

Figure 3, taken from Boring's extraordinarily careful study on himself, illustrates the close correspondence between the loss to pin and that to touch. He used the same type of instrument throughout the testing, capping it with a needle to test pain and with a hair for touch. Emphasis is placed upon this because the use of methods of dissimilar precision for testing different modalities of sensation in the same person has given rise to statements that the zones of loss of one modality are consistently and significantly greater than those of another. For example, it has been contended that in a peripheral nerve lesion, the area in which sense of touch is lost is greater than that in which pain to pin-prick is absent. Boring finds that this may be true if a punctiform stimulus is used for pain and what he calls an areal stimulus, such as a camel's hair brush, is used for touch. Such a tactic is, of course, usual in clinical examination. The converse, i.e., loss to pin greater than loss to touch, is said to be true in a lesion of adjoining posterior roots (Head and Sherren, 1905; Foerster, 1933). Studies as intensive as those of Boring will have to be performed before such statements can be given the fullest credence. If they should prove to be true an adequate anatomical explanation will then have to be sought.

The nerves concerned with the distribution of pain in the deeper tissues have not been as fully worked out as those from the skin, but it has long been known that the deep branches of a nerve may supply a dissimilar or even remote area from that supplied by its superficial branches. For example, the skin of the neck is supplied by the third, fourth and fifth cervical nerves which also convey pain from the dome of the diaphragm. Inman and Saunders (1944) have attempted a systematic presentation, Figure 4, to show the nerve supply of superficial and deep muscles and the skeleton, and have coined the term "sclerotome" for the zone of deep tissues innervated from a given spinal segment. (Compare these figures with that

Kellgren (1939), by application of a method of study which he and Lewis developed, has provided us with some precise diagrams of the segmental innervation of the deep tissues which are the most thoroughly documented data of this sort yet available. He found that the injection of 6 per cent saline into any muscle induced pain felt over wide areas which seemed to follow a segmental pattern. From different muscles supplied from a common nerve root, whether they lay on the back, front, or flank, the pain which arose was in a common area of distribution. This included both the dorsal and ventral aspects of the body. Exploring this observation further he found that injection of the deep interspinous ligament, just lateral to the midline, likewise caused pain of segmental distribution. The segment affected is directly ascertainable from the ligament involved. Beginning with the space between the fourth and fifth cervical vertebrae, corresponding

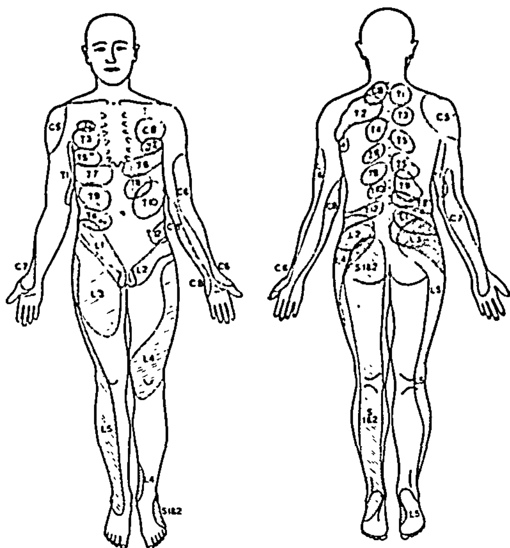


Fig. 5. Segmental innervation of the deep tissues according to Kellgren, determined by injection of 6 per cent saline just lateral to interspinous ligaments. From Lewis, 1942. Courtesy, The Macmillan Co., New York.

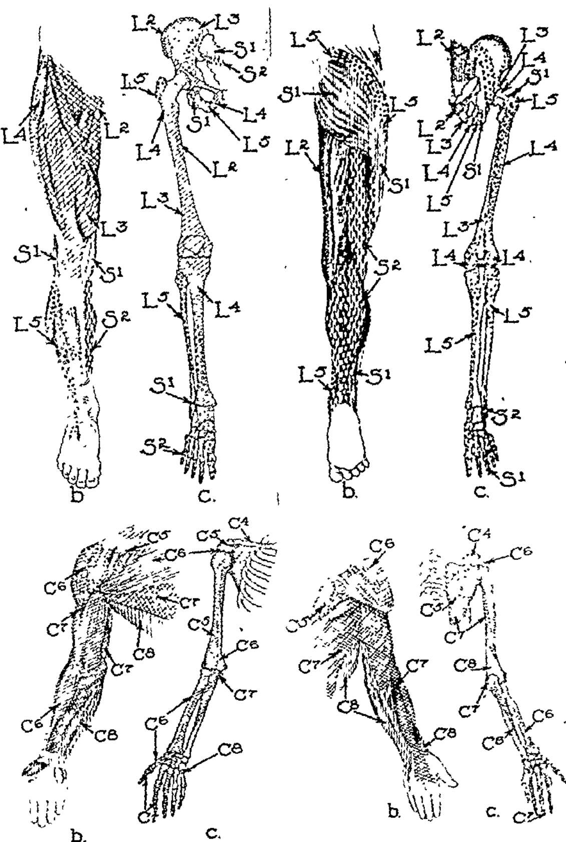


Fig. 4 Sclerotomes of the upper and lower limb

Anterior aspect of limb on left, posterior aspect on right.

From Inman and Saunders: *J. Nerv & Ment. Dis*, 1944, by permission of the editor.

E. POSTERIOR ROOTS

Surgeons working in the spinal canal under local anaesthesia have long since demonstrated that even light contact with a posterior root may cause pain referred to the area which it innervates. Conversely, as shown first by Bennet (1889) and Abbe (1889), division of a series of posterior roots is followed by anaesthesia of a corresponding area of skin. We have noted that this insensitivity of the skin and subcutaneous tissues to pain is more profound than that which follows anterolateral cordotomy, since analgesia is complete even to high voltage bipolar electrical stimulation, whereas in a cordotomized area pain is always felt following such stimulation (White, Sweet, Hawkins and Nilges, 1950). Although, as indicated above, knowledge is fragmentary regarding the deep zones of supply from any one metamere of the spinal cord, we have good evidence regarding the extent of the cutaneous supply, the so-called dermatome, in man. This has been obtained by more direct means. Head and Mackenzie independently charted the cutaneous eruptions in herpes zoster on the assumption that this was a disease confined to the posterior root ganglion and that the zone of supply of each root might be thoroughly elucidated thereby. Head's more complete work permitted him to construct a diagram for the dermatomes over the entire body (Fig. 6A). The dermal areas of neighbouring segments were shown as adjoining rather than overlapping as they have later been proven to be.

[illegible] to affect the central nervous system as [illegible] ad's careful work has been corroborated astonishingly well, in a general way, by other more positive methods. The most unequivocal tactic is that of Sherrington (1894B). He revealed the full area of supply of a given posterior nerve root in monkeys by cutting several roots of this type above and below it, so that a zone of sensitive skin was surrounded by anaesthetic skin. The dermatomes thus outlined are so large as to indicate that every point on the skin is supplied by at least two or even three posterior roots. The response of movement to a weak induction shock or to dilute sulphuric acid on the skin was taken to show that the area was still receptive to afferent impulses That areas of such an extent for a single dermatome are in fact transmitting painful impulses was proven by Foerster in man. He not only determined the boundaries of sensation following multiple contiguous posterior rhizotomies, but he at times carried out Sherrington's procedure of leaving one posterior root intact and dividing several others above and below it. He has provided us with sharp photographs instead of diagrams of the zones of sensory loss, from which it is apparent that there is gross variation from person to person in the zone of any given posterior root. But in general, the large area of

with the fifth cervical nerve, he mapped the reference of pain way down to the first and second sacral region. The results are shown in Figure 5. When these are compared with the superficial dermatomes of Foerster there is less overlap in Kellgren's areas of reference of deep pain, and much less spread of the T1 and T2 segments into the upper limb and of the L1 and L2 segments into the lower limb. Sinclair, Feindel, *et al.* (1948) have presented good evidence that injections of the type recommended by Kellgren evoke the pain he described by direct stimulation of nerve trunks lateral to the interspinous ligament, rather than by irritation of nerves at the ligament. They showed that injections confined, for example, to the thick lumbar interspinous ligaments caused only local pain in the back. This finding, however, does not invalidate the general conclusions of Kellgren regarding the distribution of referred pain at each segment. Ian MacNab (personal communication, 1950) has repeated the studies injecting only 1 cc. of 6 per cent saline to minimize spread of the solution. When used in the areas C4 to T2 and T12 to S2 this smaller amount caused pain in areas essentially as described by Kellgren with the exception that reference of pain in the S1 and S2 region did not include the lateral border of the foot.

The complex distribution of the primary afferent neurones subserving pain in the head and face will be discussed in connection with the clinical problems of cephalic neuralgia (Chapters XIV-XVI).

A further discussion of the sensory nerve supply of the deep structures and particularly of the viscera will be found in the following and later chapters. It is only necessary to emphasize at this point that the visceral pain fibres differ in no important way, except in their sparser distribution, from ordinary somatic axones which carry disagreeable sensation from other deep tissues such as fascia, skeletal muscle and periosteum. Although they run to the viscera in the splanchnic trunks they do not, according to Langley's definition, belong to the sympathetic nervous system. The visceral nerves are mixed trunks, containing sympathetic motor axones to smooth muscles, blood vessels and glands, and also afferent axones which enter the posterior spinal roots and there join pain conducting fibres of the somatic system. These fibres carrying visceral sensibility are so conveniently concentrated in the thoracic, abdominal and pelvic splanchnic trunks that true visceral pain is easily interrupted by cardiac or splanchnic neurectomy. Division of peripheral nerves, on the other hand, is rarely a practical procedure. A description of the peripheral and visceral nerves of importance to the surgeon concerned with the interruption of pain will be found in the clinical chapters below and a more complete account in the writings of Foerster (1929), Hovelacque (1927), Mitchell (1935, A and B, 1938, A and B; 1940), and White, Smithwick and Simeone (1952).

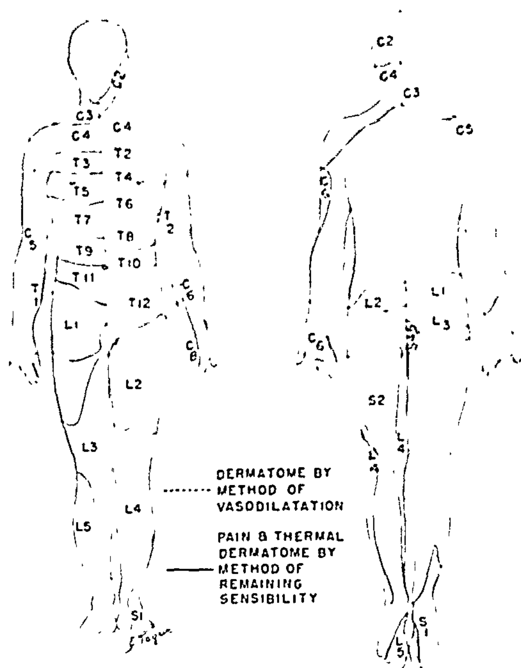


Fig. 6. B Dermatomes according to Foerster.

The continuous lines represent the extent of the pain and thermal dermatomes Variations from the recorded extent in the diagram are usually in the direction of an even larger dermatome. By Foerster's methods of testing, the tactile dermatomes were always larger than those for pain and temperature.

The sixth cervical, all five lumbar, and the upper two sacral dermatomes were delineated by dividing posterior roots both above and below the root in question The thoracic and most of the cervical dermatomes were defined by the "constructive method," i e , when a series of contiguous roots is divided the superior border of the resulting anaesthesia reveals the inferior border of the dermatome of the next higher intact root and the inferior edge of the anaesthetic area shows the superior border of the next lower dermatome Neither of these methods was available to determine the upper boundary of C3, either boundary of C5 and T1, and the lower boundary of T2 on the arm, which are represented by dotted lines, according to the extent of vasodilation upon faradic stimulation of the posterior root No datum is at hand for the seventh cervical dermatome.

Diagram compiled from data in Foerster (1933)

overlap shown by Sherrington has been confirmed and it is evident that the distribution of a single root may extend beyond the adjoining one into an area two roots removed (see Foerster's Figs. 63, 64). Utilizing somewhat limited techniques of clinical testing Foerster found that section of a single

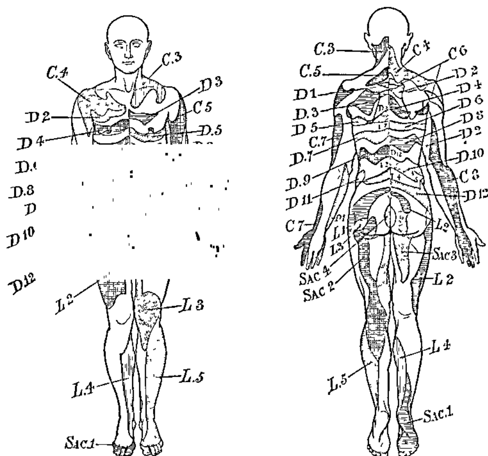


Fig 6 A The dermatomes according to Head on the basis of the cutaneous eruptions in herpes zoster.

From chapter by Sir Henry Head on "Herpes Zoster" in Allbutt and Rolleston's *System of Medicine*, vol 7, 1910 Courtesy, Macmillan & Co, London.

posterior root yielded little or no sensory loss on the skin. The individual variation is so great and the overlap in each person so pronounced that the fact cannot be conveyed on a single composite diagram and Foerster did not try to do so. At the sacrifice of depicting individual variations we have tried to summarize his studies in the diagrams of Figure 6B. When one records sensory loss in a patient, we recommend that findings be given in relation to specific anatomical landmarks rather than in accordance with the presumed location of the dermatome in that person No one else has published such data on more than a few segments in man, nor is it likely now that any one else will be able to because of the ineffectiveness of posterior rhizotomy in most clinical problems of pain. Here was a golden opportunity for improving our knowledge which did not last. As our

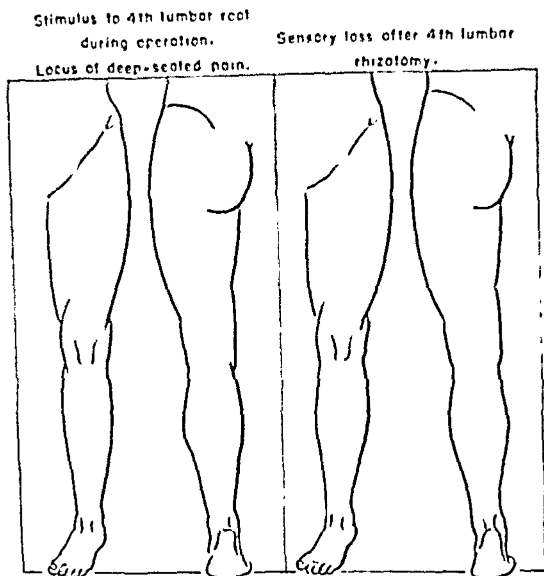


Fig 8 Areas of supply of fourth lumbar nerve determined by two different methods.

Von Reis finds the area of deep-seated pain upon direct stimulus to the fourth lumbar root to be much larger than the cutaneous zone which is hypalgesic to pinprick following fourth lumbar rhizotomy.

From von Reis: *Acta psychiat., Kbh.*, 1945. Courtesy, Ivar Haeggstrom, Stockholm.

tween this and most earlier charts is the depiction of the dermatomes to the limb as a series of continuous bands passing from the dorsal midline of the body down the arm and the leg. His zones thus ascertained are extensive, long, narrow strips which do not overlap each other significantly. He considers each zone to represent probably "the primary innervation, not the entire distribution of each nerve root." In the instances of complete lesion of the root a fainter hypalgesia extends beyond the borders shown in the chart. Falconer, Glasgow and Cole (1947) in patients with protruded discs compressing C7, L5 or S1 roots, or in individuals given an intraspinal

therapeutic armamentarium increases, procedures giving us opportunities to learn may become clinically unjustifiable. It behooves us therefore to study the total physiological effect of each of our denervations while the privilege is at hand.

Studies of the extent of certain dermatomes in localized areas following posterior rhizotomy which have complemented Foerster's data are increasing. Among these we mention Bradford and Spurling (1945), who found diminished appreciation of pinprick and of touch with cotton after section of a single posterior root. Figure 7 illustrates the degree of variation



Fig. 7. Variations in S1 dermatome.

Four cases of protrusion of the lumbosacral disc in whom posterior rhizotomy of S1 was performed within the dural sleeve. They show the variability from person to person of hypalgesia to pinprick (areas in black)

From Bradford and Spurling (1945).

occurring in four different patients in each of whom the first sacral posterior root was cut. Their figures show a similar degree of variation on section of the fifth lumbar posterior root. Von Reis (1945) also found an area of cutaneous hypalgesia to pinprick after division of a single posterior root. Figure 8 illustrates his average finding on testing with a pin in 18 instances after division of the fourth lumbar root. Hunter and Mayfield (1949) have provided us with numerous charts of the hypalgesia following division of the second cervical posterior root; these depict evidence of greater extension of sensory loss forward to the trigeminal field than any earlier studies. This will be discussed further in connection with treatment of pain in the head. Keegan (1943, 1947) (Fig 9) has given us an outline of the dermatomes on the basis of hypalgesia caused either (1) by protruded intervertebral disc; (2) by a procaine injection controlled by x-ray into individual cervical nerve roots of 10 volunteers, or (3) by posterior rhizotomy to a single nerve root in the lower extremity. The principal difference be-

anticipated extreme difficulty at such a task and are surprised that their results yield data as close to other methods as they do.

Von Reis (1945, p. 65) determined "the distribution area of deep-lying pain" of a root by pinching it when the patient was under local anaesthesia at operation. This tactic elicits pain referred to a greater area than the deep-seated pain evoked by Kellgren's injection of hypertonic saline. Figure 8 for the fourth lumbar segment thus studied shows an area even larger than indicated by the method of remaining sensibility of Sherrington. It may be, however, that this method gives an exaggerated notion of the supply of the root, because Foerster found that stimulation of the distal end of a divided posterior root causes pain. The impulses causing this enter the cord over adjoining nerve roots whose division then stops the pain. This massive artificial stimulus may cause a spread of response beyond that seen in either normal or spontaneous pathological states within the domain of a single posterior root.

Foerster (1933) also noted that he could see on the skin in man evidence of the vasodilation first noted by Stricker and Bayliss in animals on stimulation of the peripheral end of a divided posterior root. He marked out the zone so observed during many of his posterior rhizotomies. The haste with which such gross observations would have to be made on the operating table under poorly standardized conditions of skin temperature would probably not admit of the accuracy obtained by postoperative study of sensation. In general the dermatomes as delimited by vasodilation were smaller than those marked out by the method of remaining sensibility.

F. ANTERIOR ROOTS

Just as a dispute has long raged regarding the possibility of efferent fibres in the posterior roots, so claims are made periodically that there are some afferent fibres conducting impulses to the cord over anterior roots. In the ventral roots of cats Schafer (1880) has seen cells resembling those in the dorsal root ganglia. Although he was not able to find these in the dog or in man, nine other observers have seen them in numerous species and these include four who have found them in man. Windle (1931) gave an excellent summary of the literature and reported the most completely studied human material—a six to seven month foetus which showed such cells in all but 18 of the 60 anterior roots examined Fourteen of the 18 roots containing *no* ganglion cells lay above the sixth thoracic segment. No direct observation has been reported of the full course of the axones arising from these cells.

In addition to the unequivocal evidence for sensory cell bodies in the anterior roots there is other good data to show that there are afferent fibres

extrathecal procaine block at the lower two levels, obtained patterns of hypalgesia somewhat similar to those described by Keegan. Černý (1947) also finds that the patient's subjective impression of his sensory loss as outlined by him on his own skin corresponds to Keegan's dermatomes. We find it difficult to be certain in our own minds that the effect of the protruded disc or the injected procaine in these cases is confined to a single

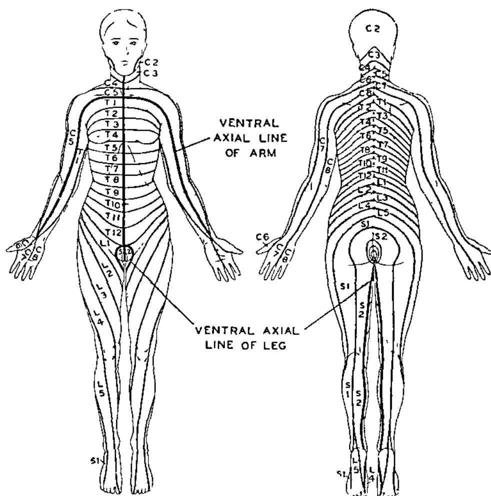


Fig. 9 Dermatome chart according to Keegan based upon hypalgesia from compression presumed to be confined to a single nerve root
From Keegan *J Neurosurg.*, 1947, by permission of the editor

root. Davis, Martin and Goldstein (1952) studied the sensory changes in 500 patients with herniated cervical or lumbar discs; they found extreme variability in the sensory patterns at each level and decried the use of such patients for determining dermatomes. Von Lanz and Calver (1938) attempted to determine the segmental innervation by direct, and exceedingly painstaking, dissection of cadavers, following the nerve fibres as far as possible. In view of the complexity of the limb plexuses we should have

Among the chief protagonists of the theory of transmission of pain over the ventral roots have been Lehmann (1921A) and Wartenberg (1928). They rest their case on a series of clinical and animal experiences as well as on reports culled from the literature in which, after extensive posterior rhizotomies, there was still evidence of pain in the "denervated" zones—usually upon strong stimulation of deep somatic or visceral structures. Without giving the details of the clinical and animal material they cite, we may point out that the interpretation that anterior roots at the same level were transmitting the pain response was never proven by division of these anterior roots and elimination of that response. That some other posterior root might well have been the avenue of the pain impulse is suggested by these facts: (1) It is disturbingly easy to overlook one or more posterior root filaments at the time of operative section. We, Groves (1911), and Meyer (1926), among others, have encountered examples of this at subsequent operation or post-mortem. (2) The structures underlying given areas of skin may be innervated from segments differing greatly from those supplying that skin. The failures to eliminate deep sensibility after thoracic rhizotomy are particularly likely to be explained on this score, because of the cervical innervation of the diaphragm, trapezius, serratus anterior and pectoral muscles. Alternatively, the cause of the pain may have been a lesion of the central nervous system, as is perhaps the case in some patients with postherpetic neuralgia, so that the original pain is not caused by impulses traversing the posterior roots. In another group of patients with amputation stumps absence of the limb precludes a check on the technical adequacy of even the cutaneous denervation. Speaking for the truth of the Bell-Magendie Law are the numerous instances both in animals and in man of absence of all deep and superficial sensation in limbs following extensive posterior rhizotomy—Meyer (1921), Sicard, Haguenau and Mayer (1926), Davis and Pollock (1930) and Wartenberg (1928), to cite a few reports. Davis and Pollock presented a striking case in which posterior rhizotomy of C4 through C8 roots produced cutaneous anaesthesia only along the radial border of arm, forearm, and thumb. Extension of the rhizotomy to include the posterior roots from T1 to T4 yielded analgesia to cutaneous and deep pain, as well as loss of touch, temperature, proprioceptive and vibratory sensation throughout the upper limb and a substantial portion of the shoulder girdle. This total loss was still present when the patient was re-examined 15 months later. They also called attention to the special suitability of decerebrate animals for studies on the completeness of denervation, since these preparations give a vigorous muscular response to the slightest stimulus. These animals showed no movement following sensory stimuli in the upper limb after division of the posterior roots from the fourth cervical down through the sixth thoracic level.

in this location. Sherrington (1894A), after sectioning ventral roots of the cat and monkey, saw a few degenerated myelin sheaths in the root central to the cut, and a few undegenerated fibres in the peripheral segment. Windle (1931) confirmed these observations in the dog and cat, as did Foerster and Gagel (1933) in the monkey and man. As to the precise function of these sensory fibres Sherrington was able to see that most of them arose from the distal end of the posterior root ganglion. Hence one might take them to represent the peripheral end of fibres receiving afferent impulses from the pia and blood vessels of the spinal cord and ventral root. These would then be conducted back to the brain via the posterior root. We have made one observation which suggests that localization of a stimulus applied to the spinal cord itself is possible. This patient repeatedly complained of pain as the pia of the anterior quadrant of his spinal cord was pricked with a knife, and he localized this pain to the precise site where we were working "deep in the back." Sherrington noted that other fine and scattered fibres in the anterior roots might be of peripheral sympathetic origin, since such fibres remain intact in the spinal nerves just peripheral to an operative division of both roots distal to the spinal ganglion, and are visible after time for degeneration of the fibres from the posterior root ganglion and from the ventral horn of the spinal cord.

However, the presence of afferent fibres in the ventral roots is not of itself proof that these structures should be cut to relieve pain, since the fibres may be taking a circuitous course to enter the cord by way of the posterior roots. This interpretation might be placed on the observations of Claude Bernard (1866) after section of the ventral roots in dogs. Stimulation of the peripheral end of these cut nerves caused "pain responses" if the dorsal root were intact, but stimulation of the central ends of the cut ventral roots caused no such responses. In our own observations at operations in man pain has at times been observed coincident with powerful muscular contraction upon stimulation to the peripheral end of the divided ventral root. This pain is referred to the area of muscular contraction and is probably related to secondary stimulation of afferent fibres in the muscle.

Frykholm (1951, pp. 62-64) came to a similar conclusion from his human material. He studied the pain sensitivity in the lower cervical ventral roots in 18 patients operated upon under local anaesthesia for relief of presumed compression of a cervical root. In 12 of these 18, mechanical stimulation of 16 ventral roots caused pain, usually severe, deep-seated and boring in character. That this pain was due to fibres entering the cord in the dorsal root was demonstrated by disappearance of the pain in the six patients in whom the dorsal root or dorsal root ganglion was anaesthetized. Muscular contractions could still be elicited from the ventral root, proving that the procaine had not spread to that structure.

usually ran between 0.1 and 2 volts. Division of the anterior root just before its emergence from the dura was carried out in 18 of these patients, and the central end again stimulated. In two-thirds of these, 12 of the 18, stimuli at 20 volts or more caused no pain. In some of this group the potential was raised to 140 volts without causing any discomfort. The other six, however, had pain at 8 volts or less and, in three of these, the threshold of 0.01 to 0.02 volts approached that of posterior rootlets. In five of the patients the pain was referred to the ipsilateral arm, elbow, shoulder or scapular region. In one patient there was an extraordinary and variable reference of pain to either or both legs or one or both sides of the torso. In each instance the anterior root was held in the air and the electrodes applied over 1 cm. from any contact of this root with other tissue so that physical spread of stimulus appeared to be excluded. Such explanation was further ruled out by eliminating the sensory response in three of the patients by crushing or ligating the root in continuity central to the point of stimulation.

In two patients upper cervical anterior roots were stimulated—C2 in one patient and C2, 3 and 4 in the other. From three of these four roots no pain was obtained upon stimulus to the central cut end at a maximum of 30 volts. Stimulus to the fourth of the roots caused no pain even when it was intact. In two other patients there was a special opportunity to stimulate many divided long anterior roots. Both had agonizing flexor spasms which precluded walking or sitting, yet had virtually no sensory loss. In one of these patients, who had multiple sclerosis, the eight right anterior roots from T11 through S1 were divided. Stimuli at 5 to 10 volts caused pain in the right lower quadrant when applied to the central end of T12, and at 10 volts caused pain down the front of the right thigh or in the right lower quadrant in the case of the central end of L1. Stimuli of 20 volts or more had to be used to evoke pain from the remaining six of these roots and from all seven of the anterior roots from T12 to S1 in the second person (who had Friedreich's ataxia). In the latter patient physical spread of stimulus was shown to be operative at these higher voltages. When the electrodes on the roots were only 2 cm. from the cord pain might occur at 20 to 40 volts, but the threshold would rise to 60 to 140 volts when the electrodes were applied at distances from 3.5 to 5 cm. from the cord.

The work of Windle suggests that at levels above T5 the anterior roots contain far fewer ganglion cells than at lower segments. In our small number of stimulations more upper thoracic anterior roots have happened to show possible afferent fibres than have the lumbosacral roots.

We should point out the fact that the occurrence of discomfort on electrical stimulation of ventral roots is not necessarily proof that pain impulses of clinically significant degree traverse them under normal circum-

Foerster and Gagel (1933) listed a variety of observations tending to the opposite conclusion which cannot be overlooked. They found that in man faradic stimulation of the central end of a divided anterior root caused pain referred to the same locality as that which occurred upon stimulation of the corresponding posterior root. The pain arising from the anterior roots was much less severe than that from the posterior roots and varied markedly in intensity from person to person. In some patients only a mild itching or unpleasantness was felt; in others there was severe pain. The number of patients and the particular anterior root in each are not given, but two instances were mentioned earlier by Foerster (1927A, p. 63). In these individuals, after section and degeneration of the sixth to the tenth thoracic posterior roots, a stimulus to the eighth anterior root at a later date still caused pain. In other cases at the time of operation, just after the posterior roots had been cut, direct electrical stimulation of an exposed cutaneous nerve within the area supplied still caused pain.

Foerster and Gagel also contended that, although they observed immediate total anaesthesia of an upper limb following division of the posterior roots from C2 to T3 or C3 to T4, there was a late gradual return of sensation. This they stated could not be explained by failure to divide the posterior roots at operation. The degree of sensory recovery varied greatly from case to case and was most likely to include recovery of deep pressure sense and pressure pain. However, they mentioned cases in which total anaesthesia of an arm gave way later to an appreciation of cotton wool, needle scratch, warm and cold objects respectively with the appropriate sensation—albeit the thresholds were higher. Appreciation of two points, localization of sites stimulated and the naming of numbers written on the skin even became possible in some of these cases. They found that posterior root section alone failed to give a satisfactory result in the majority of their cases, but that in all those with amputation or paralysis of a limb a combined anterior and posterior root section stopped the pain and yielded a persistent total loss of sensation.

Their results on stimulation in particular appear to us to be crucial and we have studied the subject further when suitable opportunity has presented itself by electrical stimulation within the spinal canal in man. In all we have studied 46 anterior roots during 30 operations. Square wave electrical impulses at 30 cycles per second of 1 millisecond duration were applied to them via bipolar electrodes. The T1, T2 or T3 anterior roots were stimulated in the course of 26 operations for anterolateral cordotomy. In seven of these patients when the nerve was in continuity no painful sensation was elicited even with signals which varied at maximum from 50 to 100 volts. In 19 operations, however, such stimuli evoked pain in the ipsilateral chest, back, axilla, arm or fingers at the thresholds which

Foerster and Gagel (1933) listed a variety of observations tending to the opposite conclusion which cannot be overlooked. They found that in man faradic stimulation of the central end of a divided anterior root caused pain referred to the same locality as that which occurred upon stimulation of the corresponding posterior root. The pain arising from the anterior roots was much less severe than that from the posterior roots and varied markedly in intensity from person to person. In some patients only a mild itching or unpleasantness was felt; in others there was severe pain. The number of patients and the particular anterior root in each are not given, but two instances were mentioned earlier by Foerster (1927A, p. 63). In these individuals, after section and degeneration of the sixth to the tenth thoracic posterior roots, a stimulus to the eighth anterior root at a later date still caused pain. In other cases at the time of operation, just after the posterior roots had been cut, direct electrical stimulation of an exposed cutaneous nerve within the area supplied still caused pain.

Foerster and Gagel also contended that, although they observed immediate total anaesthesia of an upper limb following division of the posterior roots from C2 to T3 or C3 to T4, there was a late gradual return of sensation. This they stated could not be explained by failure to divide the posterior roots at operation. The degree of sensory recovery varied greatly from case to case and was most likely to include recovery of deep pressure sense and pressure pain. However, they mentioned cases in which total anaesthesia of an arm gave way later to an appreciation of cotton wool, needle scratch, warm and cold objects respectively with the appropriate sensation—albeit the thresholds were higher. Appreciation of two points, localization of sites stimulated and the naming of numbers written on the skin even became possible in some of these cases. They found that posterior root section alone failed to give a satisfactory result in the majority of their cases, but that in all those with amputation or paralysis of a limb a combined anterior and posterior root section stopped the pain and yielded a persistent total loss of sensation.

Their results on stimulation in particular appear to us to be crucial and we have studied the subject further when suitable opportunity has presented itself by electrical stimulation within the spinal canal in man. In all we have studied 46 anterior roots during 30 operations. Square wave electrical impulses at 30 cycles per second of 1 millisecond duration were applied to them via bipolar electrodes. The T1, T2 or T3 anterior roots were stimulated in the course of 26 operations for anterolateral cordotomy. In seven of these patients when the nerve was in continuity no painful sensation was elicited even with signals which varied at maximum from 50 to 100 volts. In 19 operations, however, such stimuli evoked pain in the ipsilateral chest, back, axilla, arm or fingers at the thresholds which

the entire margin of the posterior horn. The apical group of these cells at the dorsal tip of the horn extends right into the fasciculus of Lissauer; another (reticular) group lies along the lateral wall of the horn adjoining the postero-lateral column of white matter; and an inner group along the medial wall adjoins the posterior white column (Fig. 10). These cell

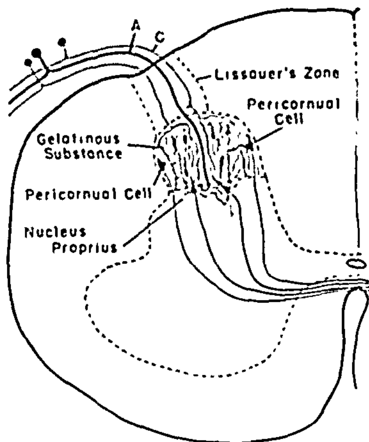


Fig. 10. Diagram of transverse section of human spinal cord to show termination of pain fibres in posterior root.

A large calibre A fibre is shown passing through the substantia gelatinosa to terminate near nerve cells in the nucleus proprius A small, faintly myelinated C fibre is shown ending within the substantia gelatinosa in relation to a pericornual cell, to one of the neurones in the nucleus proprius, or to one of the small cells within the substantia gelatinosa These latter cells may intervene in the primary afferent pathway between the entering pain fibre from the posterior root and the nucleus proprius. The long axones crossing to the opposite side and ascending the cord are represented as arising from cells of the nucleus proprius or from the pericornual group

Redrawn with slight modifications from Pearson: *Arch. Neurol. & Psychiat*, 1952 Courtesy, American Medical Association, Chicago.

groups all extend the full length of the spinal cord. Gagel finds that they show a transneuronal degeneration similar to Nissl's retrograde cell degeneration when the posterior roots are cut in man Moreover, the typical retrograde cell degeneration is seen in these cells following anterolateral cordotomy (Foerster and Gagel).

stances. We say this because of our observations on electrical stimulation of the skin rendered analgesic to pinprick by cordotomy. In such areas, no matter how complete the relief of the original clinical complaint of pain, a high voltage bipolar stimulus will always evoke severe discomfort (see p. 45). Nevertheless our results on stimulating anterior roots at operation lead us to consider it an open question as to whether in some people at one or more levels noteworthy pain impulses may not enter the cord by the ventral route. It is unfortunate that interested observers have drifted away from the problem before it has been decisively adjudicated.

We may summarize the present position by pointing out that, despite the wealth of anatomical demonstration of sensory neurones in the anterior roots, there is no positive evidence in man that pain of clinically significant degree enters the spinal cord over these roots. We know of no report of altered response to objective sensory tests after anterior rhizotomy, nor have we seen any record of relief by this procedure of pain unassociated with muscle spasm Furthermore, there have been no published accounts of failure to stop pain by posterior rhizotomy followed by success when an anterior rhizotomy was done at a later stage.*

G. SPINAL CORD

As the posterior root filaments enter the spinal cord they divide into (1) a lateral bundle of fine fibres, which branch in the marginal layer and in the substantia gelatinosa of the posterior horn, and (2) a medial bundle of large fibres. The small lateral fibres bifurcate into two short branches each at a right angle to the original and extend only a few segments rostrally and caudally in the marginal zone of Waldeyer (dorsolateral fasciculus or zone of Lissauer). In continuation of the argument that finer fibres are among those which carry the impulses for pain we point to the early papers of Ranson and Billingsley (1916) who found that section of these delicate lateral fibres in cats eliminated responses indicative of pain when the corresponding posterior root was stimulated more peripherally. Division of the medial part of the entering root left the pain responses unaltered. Hyndman (1942) has confirmed in man that an area of analgesia does in fact ensue when the zone of Waldeyer or Lissauer is divided, whereas no complete loss to touch sensation is caused by such a manoeuvre.

The entering fibres of the posterior roots terminate according to Kohnstamm (cited by Foerster and Gagel, 1932) around the so-called posteromarginal or pericornual cells, middle-sized ganglion cells which lie around

*Bucy (1950) mentions a patient described to him by Peet in whom anterior rhizotomy was said to have arrested pain which persisted after posterior rhizotomy. Peet apparently never reported the case

the entire margin of the posterior horn. The apical group of these cells at the dorsal tip of the horn extends right into the fasciculus of Lissauer, another (reticular) group lies along the lateral wall of the horn adjoining the postero-lateral column of white matter; and an inner group along the medial wall adjoins the posterior white column (Fig. 10). These cell

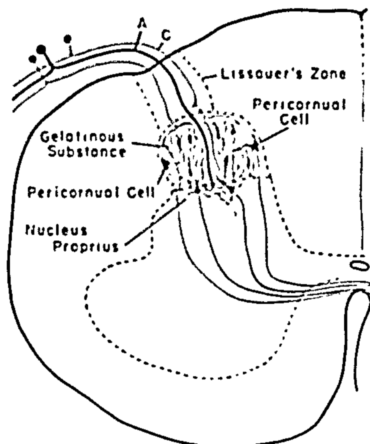


Fig. 10. Diagram of transverse section of human spinal cord to show termination of pain fibres in posterior root.

A large calibre A fibre is shown passing through the substantia gelatinosa to terminate near nerve cells in the nucleus proprius. A small, faintly myelinated C fibre is shown ending within the substantia gelatinosa in relation to a pericornual cell, to one of the neurones in the nucleus proprius, or to one of the small cells within the substantia gelatinosa. These latter cells may intervene in the primary afferent pathway between the entering pain fibre from the posterior root and the nucleus proprius. The long axones crossing to the opposite side and ascending the cord are represented as arising from cells of the nucleus proprius or from the pericornual group

Redrawn with slight modifications from Pearson: *Arch. Neurol & Psychiat*, 1952. Courtesy, American Medical Association, Chicago.

groups all extend the full length of the spinal cord. Gagel finds that they show a transneuronal degeneration similar to Nissl's retrograde cell degeneration when the posterior roots are cut in man. Moreover, the typical retrograde cell degeneration is seen in these cells following anterolateral cordotomy (Foerster and Gagel).

Pearson (1952) has recently studied the manner of termination of fibres of the posterior roots and the pattern of their connecting neurones in the spinal cord of the human baby in Golgi preparations. He has described endings of the fine fibres from Lissauer's zone not only in relation to the pericornual cells, but also to the medium-sized cells constituting the nucleus proprius of the dorsal horn and to the small cells lying within the substantia gelatinosa which caps the nucleus proprius (Fig. 10). He thinks it unlikely that any fibres of the lateral spinothalamic tract arise directly from these small neurones, although he has not traced their axones. He suggests that these cells may be intercalated between some of the primary afferent endings and the cells of the nucleus proprius or pericornual regions. The primary afferent fibres which terminate directly around these latter cells would then, he reasons, be likely to give rise to "fast pain" and those circuits in which a small neurone of the substantia gelatinosa intervened might provide a mechanism for "slow pain." This may be in addition to the possible dual mechanism relating to size of fibre to which we have already referred (p. 18).

The topographical distribution of fibres in the substantia gelatinosa has been analyzed by Szentagothai and Kiss (1949) who made small lesions in portions of posterior root ganglia and traced both the peripheral and central degeneration. Their experiments indicate that the dorsal part of a dermatome may be represented in the lateral half of the gelatinous substance and the ventral part of the dermatome in the medial half of that substance.

It has been long established that from some cells in the posterior horn axones arise which cross by way of the white commissure to the ventral and ventrolateral parts of the white matter of the opposite side of the cord, in which position they move toward the brain (Edinger, 1889). In order to determine more precisely just which cells give rise to spinothalamic tracts Kuru (1949, p. 10-11) made an especially critical study of the retrograde type of degeneration in those patients after anterolateral cordotomy who had islet-like zones of analgesia and thermanaesthesia. Examinations of their entire spinal cords revealed a striking correlation between the segments of the cord showing chromatolysis of the posteromarginal pericornual cells and corresponding dermal islands of loss of pain and temperature. Contrariwise the large cells within the posterior horn (nucleus proprius cornu posterioris) were unaffected in these segments, but they did show chromatolysis in three patients whose anterior as well as anterolateral white columns were cut and in whom degeneration in a distinct ventral spinothalamic tract could be traced. Furthermore he states that in patients in whom the posteromarginal cells below the level of operation showed the

greatest chromatolysis, the degeneration in the lateral spinothalamic tract was the greatest.

The evidence that some of these posteromarginal cells give rise to the lateral spinothalamic fibres on the opposite side is augmented by Cajal's (1909, Vol. I, p. 407) observation that the axones of some of them cross in the anterior commissure. Cajal (1909, Vol. I, p. 381) in fact finds that from nearly all of the numerous groups of cells in the posterior horn some axones pass into the commissure to cross the midline. The cells in Clarke's column and those in the substantia gelatinosa Rolandi are the only exceptions to this rule. Further careful histologic analysis by methods to trace axones may still be fruitful after anterolateral cordotomy.

Once the fibres conducting pain enter this part of the spinal cord our attempt to follow them is handicapped by their presumed small calibre and the absence of any studies with special stains or methods to identify degenerating axones. The Marchi method and its less erratic modifications, such as the Swank-Davenport method (1934), demonstrate only degenerating myelin. According to current hypothesis the pain fibres may be poorly myelinated in many of their secondary, as well as in many of their primary afferent neurones. There is, insofar as we are aware, no direct histologic means of following for long distances the course of unmyelinated and finely myelinated fibres in the central nervous system. Consequently, when we describe the course of tracts by virtue either of the positive shadows of Marchi degeneration or of the absence of myelin, when these are fully degenerated, it must be understood that we may not in fact be visualizing most of the pain fibres at all. Early animal experimentation has proven equally unhelpful in developing precise knowledge. Cadwalder and Sweet (1912) for example, after careful pre- and postoperative studies on dogs, found behaviour which they considered evidence of incomplete loss of cutaneous pain sensation and profound ataxia of the hind legs after anterolateral cordotomy. Their post-mortem material revealed incisions of the type which produce total cutaneous analgesia and no ataxia in man. They cited the work of six previous investigators who obtained contradictory results from similar animal experimentation; half of the previous workers were unable to demonstrate any definite cutaneous disturbances in their animals after anterolateral cordotomy. The work of Mott (1892) on monkeys may be mentioned in particular; neither unilateral nor bilateral division of the anterior halves of the cord produced any evidence of loss of pain sensation. It is of interest to point out that these findings in animals misled early investigators to conclude that anterolateral cordotomy would not stop pain in man.

Schiff (1858, p. 253-255) nearly a century ago found that, if only the posterior columns of the spinal cord of rabbits were left intact, the re-

mainder of the cord being divided, the animals would make a number of responses to touch, whereas they would ignore a really painful deep stimulus. Schiff recognized the similarity between this state and the clinical condition of analgesia, with preserved sensation to touch described in man by Beau and by Vieusseux (cited by Schiff, 1858, p. 253). From his further experiments he concluded that the grey matter of the spinal cord conducted the pain impulses rostrally.

In the cat the transmission of pain by short chains of neurones capable of crossing from side to side of the cord seems likely from results of Karplus and Kreidl (1925). They could not eliminate rostral responses to painful stimuli applied to the hind legs of their cats even by complete hemisections on the two sides of the thoracic cord five or more segments apart. Only when the incisions dividing the cord were four segments apart or less did the legs appear to be analgesic. It would thus seem that the bulk of somatic pain-conducting axones in many mammals, including monkeys, do not maintain a fixed position in the anterolateral columns of the cord, as is happily the case in man.

That hemisection of the cord in man is likely to produce a contralateral analgesia gradually became clear as carefully studied clinical material accumulated toward the end of the last century. Müller (1871) studied a patient with a stab wound whose lesion had completely divided one half of the spinal cord plus the posterior column on the second side. Anaesthesia to touch was present on both sides whereas analgesia was found only on the side opposite the hemisection. Gowers (1878) had an even more localized instance of trauma in which a spicule of bone was driven into the cord at the level of C3 vertebra. The injury was almost confined to the lateral column of white matter and caused contralateral analgesia with no impairment of touch. By 1902 Petrén, on the basis of an analysis of 175 cases reported in the literature, was able to present a convincing argument that the pathways for cutaneous pain and temperature cross completely to the opposite side of the cord and ascend approximately together somewhere in the lateral column of white matter. When one sees what an agonizing and exhausting task it had been to gain this fragmentary knowledge, it makes one feel remiss in not studying fully all of the results of the beautifully simple single surgical lesions we are now making as routine therapeutic procedures.

Reasonable certainty as to the precise location of the major pain pathways in the human spinal cord came only with Spiller's (1905) observation of a patient who had almost complete loss of pain and temperature sensation, but preservation of tactile sensibility and motor power in the legs. At necropsy he found a solitary tubercle at a low thoracic level in the right anterolateral column and a similar lesion at a slightly higher level on the left.

Spiller carried the proof of his thesis one stage further by persuading his surgical colleague Martin to do the first human cordotomy in January, 1911. The patient was not fully relieved of the pain associated with a tumour in the lower part of the spinal cord and had analgesia only in the legs and backs of the thighs. It remained for Frazier (1920) to demonstrate that an incision 3 mm. deep, dividing the anterior part of the lateral column at the fifth thoracic spinal segment in man, could cause analgesia to pinprick over the entire contralateral surface of the body from the lower torso downward and that such analgesia was likely to give relief of spontaneous pain in the corresponding area.

It has been shown subsequently in an exhaustive study by Häggqvist (1936) that the tiny fibres in the spinal cord, those of 2μ in diameter or less, are more numerous in the cornumarginal zones adjoining the grey matter and in the ventral part of the lateral column than elsewhere in the cord. He measured the diameters of 17,000 fibres in a single cross section of a young woman's cord at the third thoracic segment, counting samples from each of the zones numbered in Figure 11. In his zones 6 and 7, whose fibres would be divided by anterolateral cordotomy yielding contralateral analgesia, 55 per cent and 61 per cent respectively of all the fibres measure 2μ or less in diameter. The average for the whole cross section of the cord is only 42 per cent of these small fibres. This is in good agreement with our concept that such fine fibres, among their other functions, transmit pain impulses. Häggqvist's studies, however, do not help us to decide whether pain fibres lie either ventral or ventro-medial to the anterior horn, since in these regions he found the tiny fibres forming 43 to 45 per cent of the total, or about the level of the general average.

The ascending pain fibres in the anterior half of the cord have been thought by Petrén (1902) to run for four or five segments near the grey matter of the ventral horn and then to shift gradually lateralward as they ascend. Hence at any given level of the cord the caudal fibres will tend to be most superficial. Observations confirming this disposition of the pain fibres have been made by Foerster (1927A, p. 106), Horrax (1929), Wilson and Fay (1929), Grant (1932) and Falconer and Lindsay (1946)—to cite only a few. On testing sensation of patients on the operating table during cordotomy they found that, as the incision was extended to deeper levels away from the lateral surface, the analgesia on the torso tended to rise nearer and nearer to the level of the operative site Frazier's original incisions to divide the pain fibres were only 2.5 mm. deep It soon became apparent that these fibres are not so compactly assembled Babtchine (1929) found that incisions at the T4 or 5 segment 1 5 to 2 mm. deep yielded analgesia to the inguinal ligament or umbilicus and that a depth of 3 mm. was required to raise this level to the mammillary line. Banzet (1927) had

clinical plus postmortem evidence that a bilateral cordotomy at T6 dividing only the lateral half of the anterolateral column on each side (about 2 mm. deep) gave analgesia only below the knees. Even subsequent cordotomy at T5 which (as shown in microscopic sections) divided all the white fibres

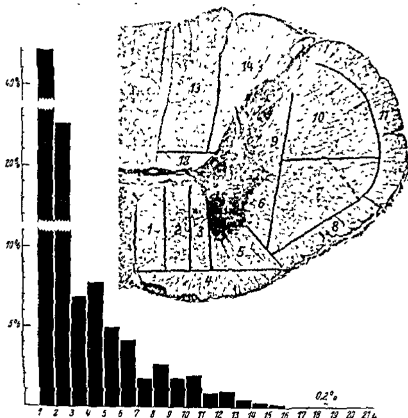


Fig. 11 Cross section of the spinal cord at the T3 segment of a 13-year-old girl

The white matter in the hemisection has been subdivided into 14 zones by Haggqvist on the basis of differing constellations of fibre sizes The adjoining histogram indicates the percentage of fibres of each diameter in the total of the entire hemisection

From Haggqvist: *Z mikr.-anat Forsch*, 1936. Courtesy, Akademische Verlagsgesellschaft, Leipzig

from the most posterior of the anterior roots to the base of the posterior horn yielded analgesia only to the iliac crest. Kuru (1949, p. 8) has recently restudied the subject by confining his cut to the smallest extent which would produce the relief of the patient's pain along with the desired analgesia to pinprick as tested at operation. He illustrates postmortem sections of 16 incisions (into as many anterolateral columns) of which only five extended ventral to the ventral horn, and none divided all white fibres lateral to the ventral horn. Although "in certain of these cases the extent of analgesic zone was as wide and enduring as in cases of the complete anterior

hemisection," in many cases the analgesia receded "more or less remarkably," became patchy, disappeared entirely or was not present right after operation. In general, surgeons at first incised only 2.5 to 3.5 mm. in depth into the anterolateral column (Stebbing, 1929; Beck, 1929; Babtchine, 1929; Peet, 1926; Oldberg, 1932; Grant, 1930). But when patients under local anaesthesia failed to show the desired upper level of analgesia with such cuts, numerous workers began to report that a deeper slice was likely to raise the level.

Kahn and Peet (1918), Horrax (1929), Kahn (1933), Hyndman and Van Epps (1939) and we with Hawkins and Nilges (1950) have confirmed beyond any doubt that pain fibres may lie at a depth greater than 3 mm. On direct stimulation in man with tiny bipolar electrodes placed in the substance of the anterior quadrant we obtained just as many responses of pain and temperature at depths of 3 and 4 mm. as at 1 and 2 mm. from the lateral surface. Weaver and Walker (1941), from a study of Marchi degeneration after commissural myelotomy in monkeys, demonstrated the same tendency for fibres arising from the highest segments to lie more medially, but pointed out that there is a large overlap in this topical arrangement. The overlap (at least of the well myelinated pain fibres) was beautifully demonstrated by Stookey (1943) in two instances of ascending degeneration. Sections at the C2 segment, the first from a case of transection of the cord at T12 and the second from a low cervical cord injury, show a strikingly similar lateral position and extent of the degenerated fibres with no more medial accumulation of thoracic fibres in the second case. This overlap is, in fact, so pronounced that, in our stimulations at various points in the anterior half of the cord, we found gross irregularity in the topical disposition (Sweet, White, Selverstone and Nilges, 1950).

Spiller thought at one time that the pain fibres lay in a bundle superficial to those for temperature. At his suggestion Fay attempted to cut only these pain fibres, testing the patient between each fractional increase in the incision's depth. In his first case (Wilson and Fay, 1929) he did succeed in producing progressively higher analgesia or hypalgesia up to T10 sparing temperature sensation by a succession of shallow incisions reaching finally to a depth of 2 mm. But in the second case (tested on the operating table by Spiller himself) a small superficial incision which produced analgesia only over the lower two-thirds of the lower leg and the sole of the foot eliminated sensation of temperature as well; and a second deeper incision extended loss of all these modalities equally. Stookey (1929) achieved the production of analgesia without thermanaesthesia in four patients. He thought that temperature sensation was carried by fibres ventral to those he cut in the anterolateral column. Grant's (1930) deliberate attempt to spare temperature fibres on the assumption that they

lay deeper than the pain fibres, also succeeded in one patient who showed analgesia from T10 downward, but thermanaesthesia only in the L5 and S1 segments. Foerster and Gagel (1932) noted also that in an occasional patient after unilateral cordotomy there might be analgesia along with little if any thermanaesthesia. Frazier and Spiller (1923) reported the reverse situation in a person with an extramedullary mid-cervical tumor, i.e., appreciation of heat and cold greatly impaired on the opposite side of the body, but that of pain normal These, however, appear to be isolated instances. Most subsequent reports are consonant with Banzet's (1927) findings: in 23 cases after cordotomy the territories of analgesia and thermanaesthesia were superimposable, in nine instances the analgesia was more extensive and in eight the thermanaesthetic area was larger (see p. 258 for our similar results) Kuru (1949), who made relatively shallow incisions, *found dissociation of pain from temperature in only three of 30 cases of* cordotomy and in one case of bulbar spinothalamic tractotomy. The conclusion that there are not two distinct bundles for the modalities of pain and temperature is supported by our findings of intermingling of these sensations on bipolar electrical stimulation within the anterior half of the cord in man.

Foerster and Gagel (1932) have contended that the pain fibres cross to the opposite side and start to move rostrally within one segment of the level at which their posterior root enters the cord. They show pictures of the zone of analgesia in 16 patients to prove this point. However, we have both pathological and clinical evidence to show that even if the whole anterior half of the cord is divided on one side the level of complete analgesia may be five to eight segments below the level at which the incision was made (Fig 68B, p 215). On the other hand, in Figure 68A, which shows a somewhat *less extensive transection of the anterolateral* quadrant, *analgesia* rose to a level within two spinal segments thereof Hence, in some instances at least, the ascent of primary pain fibres in the dorso-lateral tract of Lissauer or of secondary pain fibres in the process of crossing to the opposite side requires more than two cord segments. Sjoqvist (1949), who has made extensive incisions from the dentate ligament well medial to the zone of emergence of the anterior roots, concurs with us that such lesions will not necessarily yield analgesia to within a segment or two of the level of the cut. In his 54 cases the difference in segments between incision and analgesia was: one in four cases, two to three in 25 cases, three in 19 cases and four in six cases. Similarly in Banzet's (1927) carefully studied 30 cases, three to four segments were usually required for complete crossover of the fibres.

There is also evidence from a variety of sources in man that all of the pain pathways may not cross to the opposite side of the cord or brain stem

on their way rostrally. The most striking cases in this category are those reported by French and Peyton (1948) and by Voris (1951); the analgesia in each of these patients was exclusively ipsilateral following upper thoracic anterolateral cordotomy. In our patients in whom we stimulated with electrodes lying within the anterior half of the spinal cord, 17 per cent of the stimuli yielded pain referred ipsilaterally or bilaterally (Sweet, White *et al.*, 1950). Utilizing this observation we have stopped one-sided pain by an ipsilateral cordotomy when two contralateral transections had failed to provide relief. Kroll (see Foerster and Gagel, 1933) found in many patients after unilateral cordotomy that ipsilateral pain sensation was impaired below the level of the lesion. He noted that the number of pain points per square centimetre may be reduced, the threshold of individual pain points elevated, and the chronaxie of pain points lengthened. In the same paper the authors stressed the bilateral transmission of pain impulses from the viscera, stating that a bilateral cordotomy is required to relieve pain of such origin. We doubt the validity of this observation, as in a number of individuals we have been unable to evoke pain by distension of the renal pelvis on the side of cutaneous analgesia after a unilateral cordotomy. Distension of the gut by a balloon has also been ineffective in producing pain on that side.

Certain forms of stimuli applied to the posterior and the posterolateral columns may also give rise to disagreeable sensation. A minute electrical stimulus or a mechanical pricking of the column of Goll in man suffices to cause severe tingling, a sensation like an electric shock referred to the ipsilateral leg; the same sort of sensation is referred to the ipsilateral arm on stimulation of the column of Burdach. Foerster and Gagel (1932) noted this and we have repeatedly confirmed their statement. We have also found that similar sensations, but at higher thresholds, are referred contralaterally on stimulation of the surface of the posterolateral column. The following observations suggest that these areas of the cord may be active in transmitting pain impulses following anterolateral cordotomy in man.

1) We have found that vigorous stimulation, as with bipolar electrodes providing current at 100 or more volts, consistently causes pain in an area analgesic to pinprick; of more than 40 patients subjected to such stimulation not one has failed to describe the experience as intolerably painful, although many of them have found difficulty in describing the type of pain felt. The same type of stimulation in our hands causes no pain in an area on the trunk rendered anaesthetic by extensive posterior rhizotomy. We are in complete disagreement with observations of Foerster and Gagel (1932) who state that a faradic current causes no pain in a zone rendered analgesic by cordotomy—only a "pure sense of vibration."

2) One patient with left-sided analgesia to pinprick from the mid-

lay deeper than the pain fibres, also succeeded in one patient who showed analgesia from T10 downward, but thermanaesthesia only in the L5 and S1 segments. Foerster and Gagel (1932) noted also that in an occasional patient after unilateral cordotomy there might be analgesia along with little if any thermanaesthesia. Frazier and Spiller (1923) reported the reverse situation in a person with an extramedullary mid-cervical tumor, i.e., appreciation of heat and cold greatly impaired on the opposite side of the body, but that of pain normal. These, however, appear to be isolated instances. Most subsequent reports are consonant with Banzet's (1927) findings: in 23 cases after cordotomy the territories of analgesia and thermanaesthesia were superimposable; in nine instances the analgesia was more extensive and in eight the thermanaesthetic area was larger (see p. 258 for our similar results). Kuru (1949), who made relatively shallow incisions, found dissociation of pain from temperature in only three of 30 cases of cordotomy and in one case of bulbar spinothalamic tractotomy. The conclusion that there are not two distinct bundles for the modalities of pain and temperature is supported by our findings of intermingling of these sensations on bipolar electrical stimulation within the anterior half of the cord in man.

Foerster and Gagel (1932) have contended that the pain fibres cross to the opposite side and start to move rostrally within one segment of the level at which their posterior root enters the cord. They show pictures of the zone of analgesia in 16 patients to prove this point. However, we have both pathological and clinical evidence to show that even if the whole anterior half of the cord is divided on one side the level of complete analgesia may be five to eight segments below the level at which the incision was made (Fig 68B, p 215). On the other hand, in Figure 68A, which shows a somewhat less extensive transection of the anterolateral quadrant, analgesia rose to a level within two spinal segments thereof. Hence, in some instances at least, the ascent of primary pain fibres in the dorso-lateral tract of Lissauer or of secondary pain fibres in the process of crossing to the opposite side requires more than two cord segments. Sjoqvist (1949), who has made extensive incisions from the dentate ligament well medial to the zone of emergence of the anterior roots, concurs with us that such lesions will not necessarily yield analgesia to within a segment or two of the level of the cut. In his 54 cases the difference in segments between incision and analgesia was: one in four cases, two to three in 25 cases, three in 19 cases and four in six cases. Similarly in Banzet's (1927) carefully studied 30 cases, three to four segments were usually required for complete crossover of the fibres.

There is also evidence from a variety of sources in man that all of the pain pathways may not cross to the opposite side of the cord or brain stem

1) in the medulla (Schwartz and O'Leary, 1941, 1942; White, 1941); 2) in the upper pons (Dogliotti, 1938), and 3) *in the mesencephalon* (Walker, 1942C). According to the results of Marchi staining of human material after operative or other lesions involving the anterior half of the cord, the myelinated spinothalamic and spinotectal fibres lie in the closed portion of the medulla (that part below the obex) just ventral to the spinal trigeminal tract and its nucleus. It is in this zone of the medulla that they are accessible to operative section. The emergent fibres of the cranial portion of the eleventh nerve lie at *the junction of the descending trigeminal* tract dorsally and the spinothalamic fibres ventrally, providing the surgeon with a convenient external landmark (Fig. 70). More rostrally in the medulla (Foerster and Gagel, 1932, Fig. 40) they lie just dorsal to the inferior olive and ventral to the emerging rootlets of the vagus (see Fig. 12B, taken from Kuru's Fig. 51). In the lower pons the myelinated pain-conducting fibres are far from the surface just lateral to the trapezoid *bodies. In the upper pons (Fig. 14A) they are superficial again between* the pia and the lateral lemniscus, with whose fibres they mix in the lower mesencephalon (Fig. 14B; Kuru, 1949, Fig. 61). The spinotectal fibres move dorso-medially into the upper and lower quadrigeminal bodies, leaving scarcely any visible degenerating fibres to constitute the spinothalamic tract. In the upper midbrain (Fig. 14C) this remnant lies just beneath the brachium of the inferior colliculus (Kuru, 1949, Fig. 62), and the disappointingly few *identifiable* fibres which *remain* enter the *posterior* part of the ventral nucleus of the thalamus (Walker, 1940). Excellent detailed drawings and photographs of this course are given by Rasmussen and Peyton (1941), from which our Fig. 14 comes, and the fibres may be followed readily in Riley's (1943) beautifully labelled atlas.

On testing sensation on the operating table, after division of the pain pathways in the medulla oblongata, one finds again that the fibres from the more rostral parts of the body lie more medially, just as they do lower down (Schwartz and O'Leary, 1941). We have repeatedly confirmed this. In one particularly cooperative man, we found that progressive deepening of the incision into the bulb steadily raised his level of analgesia from the upper chest to higher segments. But on the operating table he could still, at a depth of 5 mm., appreciate pinprick over the head of the humerus. Only when the incision was carried to 6 mm did he have analgesia up to the ramus of the mandible. This receded during the first month after operation to a level just above the clavicle. Adams and Munro (1944) give us in three cases illustrations of operative lesions in the region of the medulla. Although incisions to a depth of 5 mm. and 6 mm. yielded analgesia only to the fourth and fifth thoracic segments respectively, postmortem microscopic sections showed such a narrow dorsoventral extent to the cut that

thoracic region downward following right-sided cordotomy stepped on a nail, running it into the sole of the left foot. This caused a tingling sensation referred to the foot accompanied by flexion of the leg. The sensation was similar to that at operation when the posterior column was stimulated.

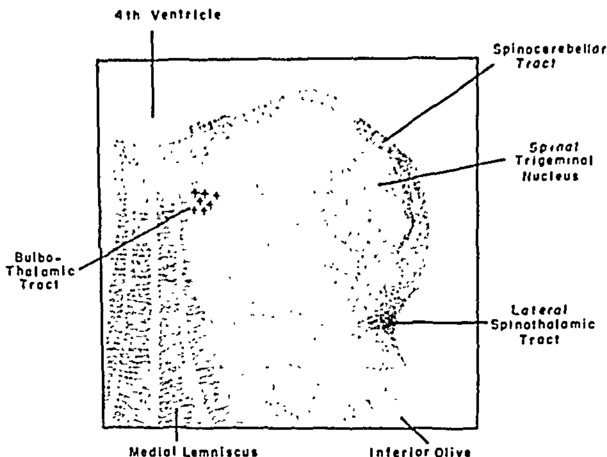
3) The pain and discomfort upon distension of the smooth muscle in the rectum and bladder (White, Verlot and Ehrentheil, 1940) and upon spasm (cramping) of striated muscle in the lower limbs (see p. 267) are not relieved by extensive bilateral upper thoracic anterior cordotomy. On p. 423 we cite the case of a woman with bilateral analgesia to the cervical segments who can still feel a burning sensation in her urethra when she has recurrent attacks of cystitis. The impulses responsible for pain in all the foregoing instances presumably must travel in the posterior half of the spinal cord

H. BRAIN STEM

1. Medulla Oblongata and Pons

The ascending fibres in the anterior half of the cord in man which are large enough to be demonstrated by Marchi stains include only superficial bundles, two of which can be followed to the thalamus (Kuru, 1949), another terminating in the superior and inferior colliculi and in the medial geniculate body (Ariëns Kappers *et al.*, 1936), and still another ending in the olive. Some or many of the fibres in these myelinated spinothalamic, spinotectal and spino-olivary tracts may well be associated with pain. They are almost entirely concentrated in areas along the outer 1 to 2 mm. of the anterolateral and anterior columns, as shown clearly in illustrations of sections just above the level of the lesion (see Goldstein, 1910; Foerster and Gagel, 1932, p. 24, ff; Walker, 1940; Gardner and Cuneo, 1945). Moreover as one moves rostrally in the bulb the degeneration remains strikingly near the surface. Foerster and Gagel (1932) illustrate (Fig. 12A) an exclusively superficial Marchi degeneration even at low bulbar levels where many spinocerebellar fibres are intermixed with the spinothalamic paths. Figure 12B taken from Kuru (1949, Fig. 54) shows the osmic acid staining in the medulla more rostrally at the level of the inferior olive in a patient with softening of the whole anterior half of the cord at the fourth, fifth and sixth cervical segments. The lateral spinothalamic tract proves to be a minute bundle about 1 mm in diameter. But since surgical experience has shown that many fibres conducting pain extend to a depth of 5 to 6 mm. in this region, and at least 4 mm deep in the thoracic cord, it is evident that the pain pathways are by no means coextensive with those shown by Marchi degeneration.

That the area of degeneration does, however, give a clue to the position of the pain fibres has been shown by the results of operative section:



B. This drawing taken from Kuru's Figure 54 illustrates the tiny volume of the lateral spinothalamic and spinotectal paths at the level of the inferior olive, even when all pain fibres in the anterior half of the cord below the C4 segment have degenerated, the patient had a softening of the anterior half of the C4, 5, and 6 segments. Kuru also illustrates in the original figure faint Marchi granules in a much more extensive area directly medial to the lateral spinothalamic tract, and extending dorsomedially as a tongue into the medial lemniscus. He calls this latter the ventromedial spinothalamic tract and does not consider it a pathway for pain.

We have also superimposed on this figure, and on those of 14 A, B, and C, the data from Wallenberg's (1901) *illustration showing the course of what he called the secondary trigeminal* pathway, which we have labelled the bulbothalamic tract, since it probably includes afferent impulses carried in the nervus intermedius, glossopharyngeus and vagus.

From Kuru, 1949. Courtesy, Sôgensya, Tôkyo and Ôsaka.

pain fibres were probably intact both dorsal and ventral to the incision. In our first case of bulbar tractotomy of the crossed pain fibres at the inferior olive (White, 1941), incision to a depth of 4 mm. was followed by postoperative analgesia up to and including the midline of the upper limb and the third finger (C7 segment).

As the area of destruction in the lower medulla extends more deeply, the analgesia rises still higher and may include the face (Fig. 13). Even below the level of the obex, as we have seen on several occasions, the secondary afferent neurones from the spinal trigeminal nucleus may cross promptly to the opposite side and then lie medial to and in the same general



Fig 12 Marchi degeneration in the medulla

A. This photograph from Foerster and Gagel's Figure 29 shows a superficial three-cornered zone of Marchi degeneration just ventral to the spinal trigeminal tract and nucleus The artist has surrounded this with black dots. Many spinocerebellar fibres are admixed with spinothalamic and spinotectal fibres at this level. The patient had undergone bilateral cordotomy at the fourth thoracic segment, which had yielded analgesia and thermanaesthesia to the lower border of the T5 segment.

From Foerster and Gagel. Z *ges Neurol Psychiat*, 1932 Courtesy, Springer-Verlag, Berlin

patient an incision just dorsal to the inferior olive to a depth 6.5 mm. yielded analgesia only to the nipple line. The incision was then carried more dorsally so that its superficial part entered the descending trigeminal tract causing ipsilateral facial pain. Testing then disclosed that analgesia had risen contralaterally to slightly above the border of the mandible. The more dorsal position of these deeper pain fibres was borne out in his subsequent cases.

Wallenberg (1896) and van Gehuchten (1901) have adduced evidence that the secondary afferent pathway for pain from the face lies dorsal as well as medial to the spinothalamic fibres, and well dorsal to the medial lemniscus. This work, on rabbits, was later confirmed in a human autopsy (Wallenberg, 1901). In Figure 12B we show Wallenberg's notion of the location of these secondary fibres from the nucleus of the descending trigeminal tract. Since we now know that this nucleus receives the pain fibres from the nervus intermedius, glossopharyngeus and vagus, as well as trigeminus, it is more properly termed a bulbothalamic tract than a quinto- or trigeminothalamic tract. Wallenberg's (1901) patient had an area of softening affecting the ventral two-thirds of the nucleus and descending trigeminal tract. The softening was maximal at the cross-sectional level of the obex and, although it was only 5 mm. long, Wallenberg's illustrations from the material at autopsy five years after the ictus show the course of the tract as a zone of absence of fibres in Weigert preparations. At the level of the fourth ventricle the fibres have crossed to the opposite side and lie just ventral to the hypoglossal nucleus surrounding ventrally moving fibres of this nerve. As they move rostrally they shift laterally in the dorsal part of the reticular formation and separate into two bundles by the time the pontomesencephalic junction is reached.

Re-routing of pain impulses: Lesions which permanently destroy the original pain pathway may not prevent pain impulses from reaching the sentient areas by some other avenue. We have evidence from some patients that pain impulses initiated by pinprick may eventually find entirely new pathways once the secondary afferent neurones in the medulla have been attained. In two of our bulbar tractotomies an extensive contralateral analgesia was still present two years after the operation, from T4-S5 in Edward D. (Table XXVI) and from C4-S5 in Percy J (Table VIII). (In the latter, additional involvement of the ipsilateral bulbar trigeminal tract was incidental to spinothalamic section for phantom pain in an upper limb.) This contralateral analgesia was replaced five years postoperatively in both patients with a capacity to distinguish pin-point from pin-head. A slight spreading "irritating feeling" in the region of the prick was experienced by Edward D. A test tube filled with ice now caused this same type of sensation, without a feeling of cold, in the previously

area with the pain fibres from the trunk and torso. From studies of the lesions after thrombosis of vessels supplying the bulb, one finds that extensive destruction throughout the bulbar reticular formation and adjoining the lateral fossa of the medulla at the level of the upper part of the inferior olive or higher produces a contralateral hemianalgesia including all or part of the face (Gordinier, 1930; Hall and Eaves, 1934). When the lesion extends only about 5 to 6 mm. in from the lateral surface, sparing approxi-

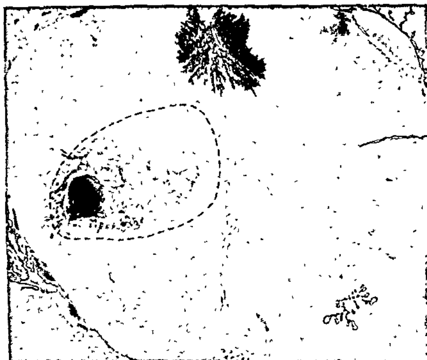


Fig 13 Lesion producing contralateral hemianalgesia including face. Section of bulb at level of inferior accessory olives at point showing most medial extent of lesion, Marchi stain with limits of lesion shown by dotted lines Patient Reginald A (Queen Elizabeth Hospital #43626). On 1/13/45 incision made to depth of 6 to 7 mm, 3 mm. dorsoventral extent and in plane 3 mm below obex. Patient awakened on operating table, analgesia throughout entire opposite head, face, neck, limbs, and torso. This was still present on third postoperative day Patient, riddled with metastatic carcinoma, died on fourth postoperative day.

mately the medial quarter of the bulbar reticular formation, the contralateral face is not analgesic but the torso and limbs are (Hun, 1897, Lüdin, 1910; Schwarz, 1912; Wilson and Winkelman, 1927). When the lesion is only 4 to 5 mm. deep, both the upper limb and the face may not be analgesic (Wallenberg, 1922; Popow, 1931, Case 1). At operation in man, D'Errico (1950) (see Chapter VIII) has found the deeper lying pain fibres from the neck and upper limb to be more dorsally situated. Thus in one

Weigert preparation, and found that it contained only about 1500 fibres belonging to the bulbo- and spinothalamic tracts. Of these 35 per cent had a transverse diameter of 4 to 6μ or larger, whereas the rest measured from 2 to 4μ. It is apparent that this pathway does not correspond at all to the concentration of fine fibres less than 2μ in diameter in Häggqvist's zone 7 (Fig. 11) of the anterolateral white matter of the cord. Future work with precise stereotactically placed stimulations and lesions in man will be needed to determine whether this small mesencephalic bundle of myelinated fibres conducts pain, "fast pain," or no pain at all.

From the data presented above it is at any rate clear that there must be many other pain fibres at this level. It will be noted that at all levels of the cord and brain stem the pain pathways are much more extensive than the myelinated portion of the lateral spinothalamic tract. However, on the assumption that all pathways for conscious perception of pain in man eventually get to the thalamus, we have elected for the sake of brevity to refer subsequently in this book to the spinothalamic tracts as those concerned among other functions with pain. By the use of this term we do not mean to imply that the pathway must consist only of a single neurone or that its fibres must have sufficient myelin to be demonstrable by stains for this substance in its intact or degenerating state. Indeed the contrary appears to be likely for many of the pain fibres.

The bulbothalamic fibres in the midbrain of man are, according to Wallenberg, much more medial than Walker places them. We have copied onto our Figure 14 Wallenberg's impression of the locus of these fibres which he sees as two separate bundles. In Figure 14A the dorsolateral bundle lies at the ventrolateral border of the mesencephalic root of the trigeminal nerve. The further course through the midbrain of these two groups of fibres—one ventromedial to the other—is seen in Figures 14B and C.

I. THALAMUS

A tiny remnant of the nerve fibres, whose degeneration is visible after lesions of the anterior half of the cord, can be seen rostral to the mesencephalon, terminating in the nucleus ventralis posterior of the thalamus (Fig. 14D). From the work of Le Gros Clark (1936) and Walker (1938) in lower primates it appears that the fibres from the lower segments of the body terminate in the external part of the nucleus ventralis posterolateralis, whereas those from the upper limb and neck end in the medial portion of this nucleus. Fibres from the face probably wind up in the nucleus ventralis posteromedialis (arcuate nucleus). This work in animals has served to

analgesic, thermanaesthetic area. In Percy J. a pinprick felt like a spreading, deep uncomfortable feeling in the general area near the point when applied almost anywhere in the previously analgesic zone. In neither of these patients was there a disagreeable quality to the stimulus of touch in these regions. The recovery of this form of painful sensation in these patients throughout the previously analgesic area, after a two year period of persistence of analgesia, points, we think, to a taking over of some transmission of pain by other pathways not originally concerned therewith. Recovery of some previously contused fibres is not a tenable explanation for the phenomenon The capacity for development of new pain pathways via secondary afferent neurones appears to be better developed in the bulb than in the spinal cord.

2. Mesencephalon

In the midbrain the Marchi degeneration seen by Walker in macaques following lesions of the spinal trigeminal tract and nucleus was confined to the superficial 2 mm. at and just dorsal to the lateral mesencephalic sulcus Wallenberg and van Gehuchten, using the same method in rabbits, found the degenerated fibres lying exclusively adjoining the central grey matter around the aqueduct and lateral to the nuclei of the third and fourth cranial nerves. Although the pain fibres may not all lie this deeply in higher primates, in the chimpanzee they are diffusely distributed at the level of the midbrain, if one may take as typical the results of Sjöqvist and Weinstein (1942) after incisions in two animals, Alice and Johnnie. Histologic sections showed that the operative lesion in Alice interrupted all of one lateral spinothalamic tract and all but the medial tip of the medial lemniscus at the level of the inferior colliculus. Johnnie's lesion is not described precisely but caused more extensive motor dysfunction than Alice had. Sjoqvist (1949) comments that both chimps at first had a complete hemianaesthesia for all qualities of sensation, but he adds, "it was astonishing to what a high extent these animals recovered from their sensory loss. After a week they were able again to feel pinprick . . . a needleprick set up a violent scratching as if the animals had felt itch or tickling."

In the midbrain of man, on the basis of their studies of Marchi degeneration after mesencephalic tractotomy and cordotomy, Glees and Bailey (1951) identified the small bundle at the level of the superior colliculi (see Fig. 14C), which is all that remains of the long pathways after the spinotectal fibres have been given off. Their identification corresponds with that of earlier workers (Riley, 1943, p. 160). They then made a fibre analysis of this area, only 0.65 mm. in cross section in a normal human

Weigert preparation, and found that it contained only about 1500 fibres belonging to the bulbo- and spinothalamic tracts. Of these 35 per cent had a transverse diameter of 4 to 6μ or larger, whereas the rest measured from 2 to 4μ. It is apparent that this pathway does not correspond at all to the concentration of fine fibres less than 2μ in diameter in Häggqvist's zone 7 (Fig. 11) of the anterolateral white matter of the cord. Future work with precise stereotactically placed stimulations and lesions in man will be needed to determine whether this small mesencephalic bundle of myelinated fibres conducts pain, "fast pain," or no pain at all.

From the data presented above it is at any rate clear that there must be many other pain fibres at this level. It will be noted that at all levels of the cord and brain stem the pain pathways are much more extensive than the myelinated portion of the lateral spinothalamic tract. However, on the assumption that all pathways for conscious perception of pain in man eventually get to the thalamus, we have elected for the sake of brevity to refer subsequently in this book to the spinothalamic tracts as those concerned among other functions with pain. By the use of this term we do not mean to imply that the pathway must consist only of a single neurone or that its fibres must have sufficient myelin to be demonstrable by stains for this substance in its intact or degenerating state. Indeed the contrary appears to be likely for many of the pain fibres.

The bulbothalamic fibres in the midbrain of man are, according to Wallenberg, much more medial than Walker places them. We have copied onto our Figure 14 Wallenberg's impression of the locus of these fibres which he sees as two separate bundles. In Figure 14A the dorsolateral bundle lies at the ventrolateral border of the mesencephalic root of the trigeminal nerve. The further course through the midbrain of these two groups of fibres—one ventromedial to the other—is seen in Figures 14B and C.

I. THALAMUS

A tiny remnant of the nerve fibres, whose degeneration is visible after lesions of the anterior half of the cord, can be seen rostral to the mesencephalon, terminating in the nucleus ventralis posterior of the thalamus (Fig. 14D). From the work of Le Gros Clark (1936) and Walker (1938) in lower primates it appears that the fibres from the lower segments of the body terminate in the external part of the nucleus ventralis posterolateralis, whereas those from the upper limb and neck end in the medial portion of this nucleus. Fibres from the face probably wind up in the nucleus ventralis posteromedialis (arcuate nucleus). This work in animals has served to

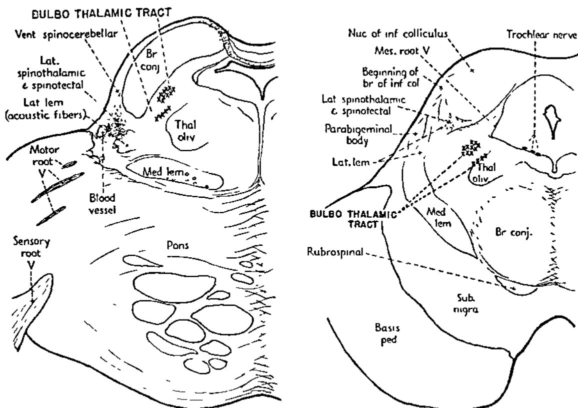


Fig 14 Course of spinothalamic and bulbothalamic fibres in the brain stem A(*left*) B(*right*)

The further course of the spinothalamic and spinotectal fibres is shown in these figures from Rasmussen and Peyton

We have added to these figures, for the upper pons and mesencephalon, Wallenberg's (1901) data for the location of what we have called the bulbothalamic tract D, *next page*, the thalamus, does not show this tract because Wallenberg was not able to follow it in the postmortem material from his patient However, he and van Gehuchten independently traced to the thalamus the Marchi degeneration of this tract after lesions of the bulbar portion of the spinal trigeminal nucleus in rabbits. Hence the designation bulbothalamic tract seems warranted

From Rasmussen and Peyton *Surgery,* 1941 Courtesy, C V Mosby Co , St. Louis

confirm evidence previously obtained from studies following vascular lesions destroying portions of the human thalamus. For example, Nicolesco (1934) found no alterations of sensation in the face when the nucleus ventralis postero-medialis was spared, whereas severe sensory alterations occurred in the contralateral limbs and trunk as a result of lesions destroying the nucleus ventralis posterolateralis. A similar topographic localization holds as well for the secondary afferent neurones in the medial leminiscus arising from the nuclei gracilis and cuneatus. The rostral ends of these fibres are intermixed with those of the spinothalamic system, but also extend further forward in the nucleus ventralis posterior.

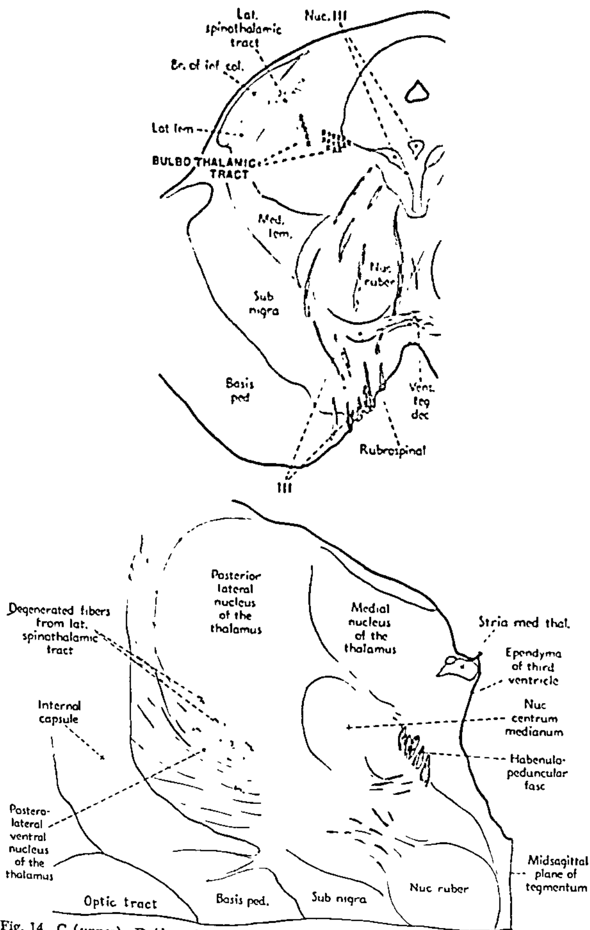


Fig. 14. C (*upper*). D (*lower*).

Walker (1938, p. 172) has demonstrated in the monkey and chimpanzee that these same thalamic nuclei project in corresponding fashion to the postcentral gyrus of the same cerebral hemisphere, i.e., the most medial parts of the nucleus ventralis posterior send fibres to the lowest part of the postcentral gyrus and the most lateral parts to the superior part of the gyrus. In other words the body from top to bottom is represented in the nucleus ventralis posterior of the thalamus from medial to lateral and in the postcentral gyrus from bottom to top. The anterior portion of this thalamic nucleus projects to the anterior deep part of the postcentral gyrus, i.e., to the posterior wall of the central sulcus (Brodmann's area 3, von Economo's area PB), its posterior portion to the anterior superficial part of the gyrus (Brodmann's area 1, von Economo's area PC). But some of this cortical area, as well as the more posterior parts of the postcentral gyrus comprising Brodmann's area 2, von Economo's PD, receive their thalamic projections largely from the nucleus lateralis posterior, which is not known to receive any direct afferent pathways from the periphery.

It is pertinent to point out that we do not know what fibres or tracts may be specifically concerned with the transmission of pain impulses beyond the termination of the secondary afferent neurones wherever they may happen to end in spinal cord, brain stem or thalamus. Hence, although the neuroanatomical and physiological literature is replete with descriptions of possible alternative pathways for pain from this point on, which might permit integration at suprabulbar levels, we prefer to forego an extended account of these until more information is available.

A description of some of the lesions and stimulations at and above the mesencephalon in man which have an effect on pain will help to indicate the complexity of the problem The data indicate that as we move more rostrally the pathways for pain become more diffuse, with a tendency to bilateral representation of any specific area, but more particularly of the face For example, it is not certain that any unilateral lesion above the level of the midbrain in man is followed consistently by an analgesia to pinprick lasting more than a week or so. Accounts of the effect of lesions at the midbrain are somewhat conflicting. Mills (1912) and Russel (1931) have each reported an instance of thrombosis of the superior cerebellar artery or one of its branches which produced a sharply-defined lesion of the mesencephalon including the brachium conjunctivum and the tissue lateral thereto, chiefly the lateral lemniscus. Each of these patients was said to have maintained a hemianalgesia till death—four years later in the first case and nine months in the second. As we remarked earlier, however, Walker noted patchy partial recovery of the pain sensation after an initial analgesia following his operative lesions in the same general region which spared the brachium conjunctivum No details of the method of examining

for pain are given in the first two cases. It is possible that Walker's intensive examinations yielded more accurate information. We have found that even when the pain pathway is cut in the medulla oblongata there may be a recovery of painful sensation to a degree which permits the patient to distinguish pinprick as exceedingly unpleasant. Furthermore this sensation is referred to a much wider area than that stimulated. This recovery required, in the two cases in which we saw it, over two years instead of weeks or months. A similar restitution of painful sensation may occur even after anterolateral cordotomy (Horrax, 1929; Peet *et al.*, 1933). The results of our own long-term follow-up examinations after spinal cordotomy (White *et al.*, 1950) suggest that such recovery must happen but rarely if an extensive incision is made. It was not clearly demonstrated in any of our cases prior to 1950, but has appeared to our regret in three recent patients.

Clinical disorders which have produced a sufficiently static thalamic lesion to permit of correlation between clinical findings and postmortem study have been vascular in nature. The thalamogeniculate artery supplies the posterior part of the lateral nuclear mass of the thalamus containing the nuclei receiving fibres from the afferent systems and projecting to the postcentral gyrus of the cortex cerebri. A thrombosis of this vessel produces the classical thalamic syndrome of Déjerine and Roussy (1906) characterized, among other features, by complete hemianalgesia. This, however, is transitory. The painful sensations, which shortly appear on pinprick or pinching of the skin, are usually worse proximally than distally in the limbs and are most pronounced on the face. Commonly such stimuli provoke unpleasant sensations which 1) come on only after a latent period of one or more seconds; 2) are localized with gross errors, even to the wrong limbs; 3) have a diffuse, irradiating, peculiarly disagreeable quality, 4) have a high threshold for their appearance; 5) persist for a more or less protracted interval after the stimulus is removed. The extraordinarily unpleasant features of sensations aroused by supraliminal stimuli apply not only to those which are normally painful, but also to other stimuli, such as contact with ice or even the touch of clothing, the pressure of a tuning fork or specific stimuli to the special senses such as the auditory system. This phenomenon often progresses to the state of spontaneous, constant or paroxysmal pain on the affected side which is no longer related to discrete external stimuli.

Even with massive lesions in which the posterior third of the lateral nuclear mass of the thalamus has been destroyed, the hypalgesia decreases steadily with time. The published figures in the autopsied cases reported to date, however, do not make it certain that the entire nucleus ventralis posterior has been wiped out. Walker, for example, illustrates preservation

of a portion of the nucleus ventralis posterolateralis in his case (1943, p. 81). Moreover, unmyelinated afferent fibres may project to other areas of the thalamus than those thus far described. Hence one is not in a position to state dogmatically that complete destruction of the thalamic nuclei on one side receiving afferent pain projections would still fail to yield a lasting contralateral analgesia. It does appear, unfortunately, that the contralateral dysaesthesias and pain tend to continue unabated—even for as long as eight years (Roussy, 1909, Case 2).

Stimulation within the thalamus of conscious man has been carried out recently by Talairach *et al.* (1949) and Hécaen *et al.* (1949) by using their specially devised method with grid and x-rays for orienting bipolar electrodes. Five of their patients had lesions causing "thalamic pain." In these stimulation of the centrum medianum of Luys, the nucleus ventralis posteromedialis and the nucleus medialis dorsalis never caused pain. The production of lesions in these areas, chiefly in the centrum medianum, was followed by marked reduction or cessation of the clinical complaint of pain along with hypalgesia or analgesia of the face and/or limbs unilaterally. In one patient with post-herpetic neuralgia coagulation of a portion of the thalamus produced hypalgesia and cessation of pain. The mechanical introduction of the electrodes into this region caused a sense of swelling and of pins and needles in the opposite hand which was, amazingly enough, not altered during the electrical stimulation preceding the electrocoagulation. Working with these patients they also found a zone in the white matter of the parietal lobe about 2.5 cm. from the superolateral surface deep to the gyrus cinguli in which weak electrical stimuli provoked violent localized lightning-like pain—evidence pointing to fibres specifically concerned with pain in the subcortical white matter.

J. CEREBRAL CORTEX

The sensory cortex has been delineated in several ways—most precisely in man by securing spoken sensory responses on stimulation. Electrical stimulation of the surface rarely causes frank pain—in only 11 out of 426 responses in the long series of Penfield and Boldrey (1937). However, nearly half of their total responses were called "tingling" or "electricity," suggesting that perhaps activity of the pain pathways is involved. Figure 15, taken from Penfield and Boldrey, shows the electrically excitable area of cortex giving rise to such sensations. This includes not only the postcentral gyrus, from which the great majority of the positive responses are obtained, but extends forward frequently to include the whole precentral gyrus and even at times a few millimeters farther forward anterior to the precentral sulcus, as well as posterior to the postcentral sulcus. They

obtained sensory responses over the precentral gyrus more frequently than motor responses from the postcentral gyrus. Foerster (1927) previously mentioned evoking pain upon electrical stimulation of the superior parietal as well as postcentral gyri. No ipsilateral sensory responses were obtained by either Penfield and Boldrey or by Foerster, but responses were referred bilaterally at times from the areas for the face, tongue and eyes in the experiences of the former authors. Bilateral pressure sensations encircling

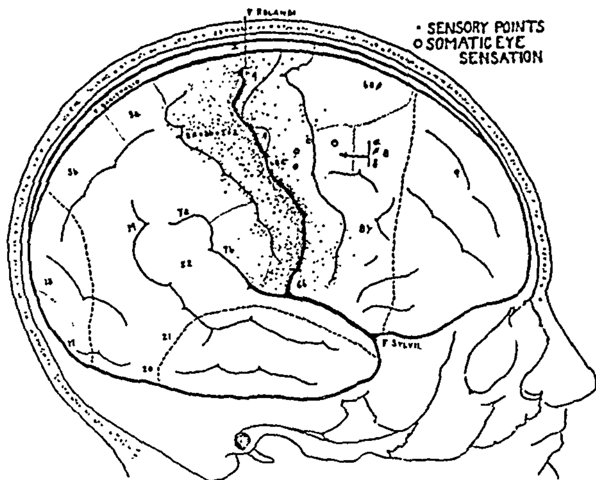


Fig. 15. Penfield and Boldrey's chart of sensory responses in man.

Each black dot represents some form of sensation upon stimulation at that point, dot within circle sensation in the eyes.

From Penfield and Boldrey: *Brain*, 1937, by permission of the editor

the entire torso were described by Foerster on stimulation of the cortical area for the trunk. Krause and Schum (Foerster, 1936, p 363) reported a long complex response to stimulation of the postcentral gyrus which included frightful pain referred ipsilaterally to an upper limb. Visceral pain is also represented in the postcentral gyrus intermixed with the rest of the afferent projection. Thus Foerster (1936, p. 363) recorded feelings of "cardiac pain" and pronounced abdominal pain from areas for the upper

and lower trunk respectively. This whole large zone delimited by direct electrical stimulation on the superolateral surface of the human cerebral hemisphere and extending over medially onto the paracentral lobule (see Fig. 16 from Rasmussen and Penfield, 1947), is now denoted as "somatic sensory area I."*

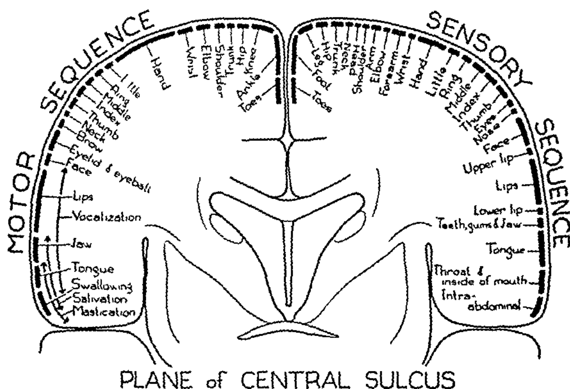


Fig 16 Locus of representation of various parts of the body in motor and sensory cortex of man.

From Rasmussen and Penfield: Federation Proc., 1947. Courtesy, American Physiological Society, Washington, D. C.

Further evidence that stimulation of portions of the cerebral cortex in man causes pain has been summarized by Michelsen (1943). He collected reports from six other authors and added five cases from the Massachusetts General Hospital. These patients complained of pain as an aura to focal seizures, spontaneous contralateral pain, or at times a dysaesthesia to many types of stimulus. In all these cases there were verified lesions appearing to implicate only the cortex, and affecting either the parietal lobe alone or that structure plus the frontal or occipital lobe.

A second method, that of "evoked cortical potentials," has given details

* "Somatic," as used by Woolsey, refers to all forms of sensation except those from the special senses of audition, vision, etc., and includes both "somatic" and "visceral" afferent impulses as connoted by Ranson. Elsewhere in this book, however, our use of the term "somatic" is not intended to include pain of visceral origin

regarding the main sensory area I and has permitted the discovery of two other separate areas as well. Electrical potential changes are recorded from the cerebral cortex consequent to physiological stimuli, including those for pain at the periphery or to electrical stimulation of peripheral nerve fibres. Adrian (1941) in the cat and Woolsey (1943) in many

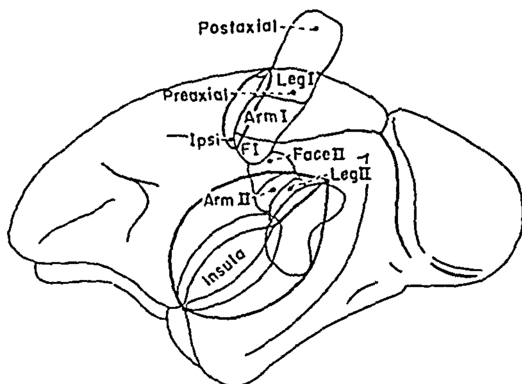


Fig. 17. Somatic sensory areas I and II in the monkey's cerebral cortex.

In this diagram of the lateral aspect of the cerebral hemisphere in the monkey, the central sulcus and the sylvian fissure are represented as having been spread apart to show the anterior and posterior lips of the cortex of the central sulcus and the upper and lower lips of the sylvian fissure. The map has been made on the basis of electrical potentials recorded from the cortex and evoked by light tactile stimuli applied to the surface of the body. The face area of somatic II is directly contiguous with the face area of somatic I. However, the two areas are distinguished by differences in latency of responses and by the detailed localization in somatic I.

From Woolsey and Fairman, *Surgery*, 1946. Courtesy, C. V. Mosby Co., St. Louis.

mammals including monkeys have found by this tactic a second smaller area, "somatic area II," where again the face, arm and leg are all represented. Figure 17 (adapted from Woolsey and Fairman, 1946) showing a monkey brain reveals the second somatic area overlapping onto the most inferior portion of the postcentral gyrus, but lying largely on the posterior part of the superior lip of the Sylvian fissure. More recently evidence obtained in a similar fashion suggests a somatic area III on the medial surface of the hemisphere posterior to the plane of the central fissure to match motor

area III anteriorly on the medial surface of the hemisphere (Woolsey *et al.*, 1952).

By this same method Woolsey and collaborators have also shown an ipsilateral representation for the face in somatic area I for the monkey and five other species; the area lies chiefly within the central sulcus. This hidden locus perhaps explains why it has not been identified in man. In somatic area II there are large contralateral and smaller ipsilateral responses throughout the face, arm and leg areas. The precise relations of this entire area to sensory function and that of somatic area III as well are unknown.

Dusser de Barenne and his colleagues (1937), using a third method, have shown in lower primates that an even larger area of the cortex is associated with sensation evoked by local application of strychnine to a

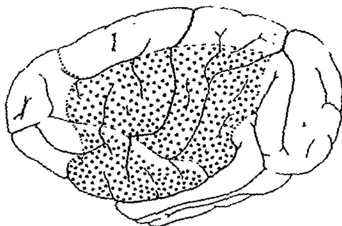


Fig 18 Sensory cortex of chimpanzee.

A composite drawing showing the extent and location of the sensory cortex and its subdivisions for leg (fine dots), arm (coarse dots) and face (rings). The regions for trunk (between arm and leg) and for neck (between arm and face) are left blank Dotted line defines anterior and posterior margins of the sensory cortex, dash-dot line, boundaries of arm-subdivision

From Bailey, Dusser de Barenne, *et al* *J Neurophysiol*, 1940, by permission of the editor

small area of the brain's surface When this drug is applied over a few millimeters of cortex in the areas concerned with the leg, arm or face the whole of the corresponding limb or face appears to be irritated. Evidence of this consists of licking and scratching movements which last for about thirty minutes. The irritation is referred to both sides of the body when only one side is stimulated, but the contralateral parts seem more affected than the ipsilateral. Large and rapid voltage fluctuations, "strychnine spikes," appear in the electrogram within this sensory region. No such response follows strychninization outside this area. Figure 18 shows the enormous extent of the sensory cortex thus ascertained by P. Bailey, Dusser de

Barenne, *et al.* (1940, Fig. 2) in the chimpanzee.

Studies in man following localized cortical extirpations reveal little reduction of pain sensation upon peripheral stimulation, and confirm the huge extent of the cortex concerned with sensation. Although Foerster (1936, p.146) emphasized that pain sensation is initially subnormal after removal of the area of the postcentral gyrus supplying either an upper or a lower limb, this sensory modality soon returns virtually to normal. Kroll (1930) describes slight changes in seven of Foerster's patients consisting of a reduced number of pain points and an increase both in threshold and in chronaxie long after the operation. Evans (1935) in his case 15, from which much of the left superior parietal lobule and corresponding postcentral gyrus were removed, still noted hypalgesia of the contralateral fourth and fifth fingers two and one half months postoperatively. In his case 17 with a less clearly definable lesion in the inferior parietal lobule there was still hypalgesia over the entire contralateral limbs and body three years later. Such findings, however, are exceptional. Recently Marshall (1951) has found gross impairment or loss both of cutaneous pain from pinprick and of deep pain from intramuscular injection of 6 per cent NaCl in focal areas contralateral to the lesion in 11 carefully selected cases of cortical and subcortical wounds. These findings were elicited from five to 34 years after the injury; hence they presumably represent a permanent loss. Guillain and Bertrand (1932) and Davison and Schick (1935) have had one and two cases respectively in which a contralateral hypalgesia was associated with lesions which included the parietal lobe but not the thalamus, as demonstrated at postmortem.

Even when an entire cerebral hemisphere is removed a degree of contralateral pain perception persists which varies from patient to patient. Thus in Dandy's two cases (1933) there was hypalgesia on the contralateral face in one and normal appreciation of pin in this area in the other. Below the face there was loss of all contralateral cutaneous sensation, but movements of joints and compression of muscles caused intense pain in both individuals. In Gardner's case (1933) 20 months after the operation gentle pinprick was recognized and localized fairly well on the opposite side of the face; firmer pressure with a pin was required below this before pain was felt. Rowe (1937) found "pain sensation preserved to some extent in scattered areas" throughout the opposite side. On the other hand, in a later case of Evans (cited by Walker, 1943) pinprick was felt in "practically normal" fashion contralaterally; normal responses had returned in the face by the fifth postoperative day. The degree of hypalgesia produced by large cortical removals clearly varies from person to person; the relatively greater preservation of facial pain is in accord with the probable greater bilateral representation of this area.

One might assume that after hemispherectomy the ipsilateral thalamus is the site of appreciation of pain on contralateral stimulation, but Walker (1943) draws attention to the fact that after hemispherectomy in the macaque and chimpanzee there is almost complete degeneration in every thalamic nucleus except those in the medullary laminae (including the nucleus centrum medianum). These latter do not project to the cortex. By virtue not only of the degree of degeneration in the ipsilateral thalamus, but also because of the prompt recovery of spontaneous pain contralaterally in man even after hemispherectomy, Walker argues ably that activity in the thalamus on the side of cerebral removal is not likely to account for the capacity to feel pain. On the other hand Hécaen *et al.* (1949), as we remarked earlier, have stopped "thalamic pain" by destruction in the centrum medianum which remains intact after hemispherectomy. An alternative explanation is that there is bilateral representation of pain pathways in the cortex and/or thalamus. We have already adduced a number of facts pointing in this direction and mention now also the work of Bychowsky and Eidinow (1934) who, upon careful testing, showed sensory disturbances on both sides in patients who had only unilateral cerebral lesions.

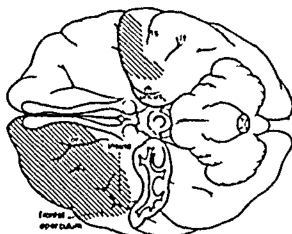
The remarkable effect upon the response of an individual to pain which follows removal of areas of cortex in the anterior portions of the frontal lobes, or after the division of white fibres underlying this portion of the brain (leucotomy) remains to be considered. The zone lies largely outside the enormous "sensory cortex" as delimited by the method of Dusser de Barenne (Fig. 18) Only Fulton (1948, 1953) has ventured to suggest on tenuous evidence that visceral afferent pathways may terminate in this part of the brain.* Yet lesions here are likely to cause an individual to take a casual, disinterested attitude to many aspects of his life including his sensations of pain. We shall consider the clinical data in subsequent chapters.

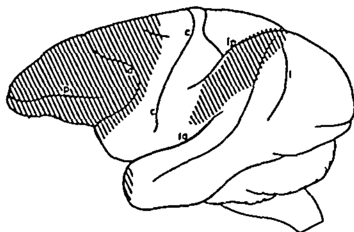
---

*Fulton points out that "the orbitofrontal cortex is the chief projection area of the autonomic system", he concludes from this "that sensory data from all the viscera are being constantly projected to this region" Hence "we have a logical explanation of why visceral pain is diminished when the orbitofrontal projections are severed, for in doing this one removes a huge afferent projection from the sphere of consciousness" We know of no evidence that stimulation of orbitofrontal cortex in man may produce pain, or that stimulus to the central end of any visceral nerve carrying many nerve fibres, such as the great splanchnic nerve, will cause synchronous bursts of change of potential within this part of the brain in animals Bailey and Bremer (1938) have evoked potentials from the posterior part of the orbital gyrus upon vagal stimulation in the cat, work which Dell and Olson (1951) confirmed

Fulton also hypothecated that the autonomic afferents, including those for pain, pass in a spinohypothalamic system on their way to the fronto-orbital cortex Downman and Amasian (1953) have confirmed this hypothalamic portion of the pathway; they found activation in the hypothalamus upon stimulation of slower fibres in the central end of the splanchnic nerve The fibres in question did not pass to the thalamus.

Brilliant studies which may be pertinent to this problem have recently been made by Starzl and Magoun (1951), Starzl, Taylor and Magoun (1951) in the cat, also by Starzl and Whitlock (1952) and French, von Amerongen and Magoun (1952) in the macaque monkey. They have determined that certain thalamic nuclei give rise to the "diffuse thalamic projection system" (Morison and Dempsey, 1942). Afferent impulses of somatic, splanchnic, auditory and visceral origin are fed into these nuclei via the reticular activating system lying in the medial brain stem. From the nuclei of this diffuse thalamic system there is distribution of the incom-





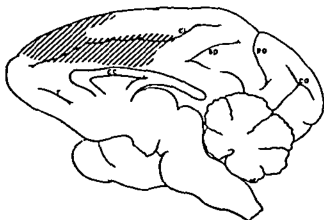


Fig. 19 Cortical areas receiving from diffuse thalamic projection system.

Cross-hatched zones show the cortical projections of recruiting waves in macacus rhesus monkey.

From Starzl and Whitlock: *J. Neurophysiol*, 1952, by permission of the editor

ing impulses via certain thalamic association nuclei. These project to almost exactly those areas of cerebral cortex whose separation or removal from the brain alters favourably the reaction to pain, i.e., mainly to the frontal lobe anterior to areas 4 and 6. Figure 19 shows the areas in the cerebrum of the macaque which receive impulses from the diffuse thalamic projection system via certain thalamic association nuclei. These workers suggest that it is disturbance of this mechanism which diminishes the affective component of sensory perception and deprives pain of its unpleasantness. This explanation would account for the favourable results from lesions both in the frontal lobes and in the medial nucleus of the thalamus, one of the principal association nuclei. The original papers must be consulted for appreciation of the details of these critical experiments and their analysis.

It will be apparent that in following the fibres which conduct pain rostrally we have become progressively less certain of their main pathways and alternative routes, and that we are quite unable to say what nucleus or level must be attained before a conscious appreciation of pain occurs. Nor do we know exactly what must be destroyed in order to cause pain, which reaches the brain, to be consciously or unconsciously disregarded.

CHAPTER III

MECHANISMS OF PAIN CONDUCTION AND PERCEPTION. PAIN TRANSMISSION BY PERIPHERAL AND VISCERAL NERVES

Investigation of the nervous system by anatomical methods has failed to give a complete understanding of the intricate mechanisms by which cutaneous or visceral pain reaches the sensorium. Physiological experimentation has carried the frontier of our knowledge much farther. The experimental subject of choice, however, is not the common laboratory animal, but man himself. The higher portions of the central nervous system are profoundly different in the cat and dog; even the chimpanzee, man's nearest living relative in the evolutionary scale, cannot tell us where or how he feels a given stimulus. Testing the sensibility of such accessible structures as skin, underlying muscle, and joints would appear to be a simple matter, but until one has read Lewis's (1942) critical study it is difficult to realize how much the keen observer can learn by modern physiological techniques.

Application of these methods has only recently been directed at deeper visceral structures such as the meninges, heart, and genito-urinary apparatus, which are such common sources of persistent pain. In the early years of the century Lennander (1901), studying sensation of the abdominal contents under local anaesthesia, concluded that the viscera were totally insensitive. Intra-abdominal sensation, as far as Lennander could discover by cutting, tearing, or burning, was confined entirely to the parietal peritoneum and roots of the mesentery, which he felt were innervated by somatic rami derived from spinal nerves. Sheehan (1933), however, has shown that the sensory Pacinian corpuscles in the mesentery and pancreas of both cat and man degenerate after splanchnicectomy, and Lewis (1942) states that "if it is asked why the nerves entering the mesentery are not to be regarded as visceral nerves, the answer comes perilously near to being that they respond to ordinary stimuli." The possibility that the viscera themselves could have sensation was not realized until Hurst (1911) showed that the physiological stimulus for producing pain in hollow organs was distension. Not until the discovery of Sutton and Lueth (1930) that anoxia of the myocardium was the physiological stimulus for cardiac pain and Lewis's (1942) production of pain in deep structures by ischaemia of skeletal muscle and the injection of hypertonic sodium chloride or buffered acid solutions

into muscles, ligaments, and joints, was the way opened for a critical study of pain from deeper bodily structures.

It is now generally realized that adequate stimuli for painful sensation include sudden distension or vigorous contraction of hollow viscera, rapid distension of the capsule of solid organs like the liver, crushing or stretching of blood vessels, and anoxaemia of functioning muscular tissue (Wilson and Mussey, 1947). In his recent book Kinsella (1948) goes so far as to conclude that there is only a quantitative difference between visceral and somatic pain. The nerve endings, which Lennander believed were confined to the root of the mesentery, extend to all the internal organs. As they are relatively few in number, it requires summation from a widespread stimulus to produce pain. Hence no sensation is produced on crushing a segment of bowel in a haemostat, while compression of the nerve endings over a larger area in a distended loop is distinctly felt. In certain circumstances where the sensory threshold is lowered, such as in acute inflammation, Kinsella has observed that simple digital compression of the appendix causes definite pain. He has found the same to be true of inflamed peptic ulcers. Even the normal gastric wall can be made sensitive to tactile stimuli if the mucosa is first irritated by mustard (see footnote, p. 80).

In recent years a new field has been opened by surgeons with physiological training who have studied the sensibility of deep structures under local anaesthesia, observing the effects of direct stimulation of the sympathetic ganglia or splanchnic nerves, or of their selective block with procaine hydrochloride and permanent interruption by alcoholic block or resection.

A. PRODUCTION AND APPRECIATION OF PAIN

Pain, in its final analysis, is a warning signal against potential or actual damage to tissue cells (Trotter and Davies, 1913). Different portions of the body vary widely in their sensitivity to pain and the stimuli whereby it is produced. Certain structures, such as the cornea, teeth, and arteries, have little capacity for appreciating any other stimulation than pain. The ordinary stimuli which arouse discomfort over the surface of the body require no description. The area of maximum sensitivity to pricking, scratching, cutting, pressure, or extremes of heat and cold extends with minor variations over the entire cutaneous surface and to the mucous membranes of the mouth, pharynx, larynx, the nasal cavity with its sinuses, and the middle ear. The mucosa in these last-named areas is innervated by the trigeminal, nervus intermedius, glossopharyngeal, and vagus nerves. In the lower apertures acute forms of cutaneous sensation extend inwards over the limits of stratified epithelium in the anal mucosa, lower urethra, and vagina, all innervated by the pudendal nerve.

Appropriate stimulation of the deep structures such as fascia, striated muscle, periosteum, joints, arteries, and all the viscera gives rise to little sensation other than pain. The only exception is the oesophagus, which has some appreciation of heat and cold. The threshold of sensation in these areas is remarkably stable in different individuals and in the same person when tested at different times (Wolff and Wolf, 1948).

The sensory threshold is, however, greatly reduced in inflammatory states, as surgical experience has demonstrated in the course of opening an abscess or handling coils of intestine under local anaesthesia in a case of peritonitis (Kinsella, 1948). Skeletal muscle, as Lewis observed, has such a sparse supply of pain receptors that it may be incised or have a needle passed through it "almost, if not quite painlessly." Lewis, who made his observations on normal individuals, failed to observe its increased sensitivity in the presence of inflammation. Under these circumstances even the infiltration of procaine may become an intensely painful procedure. This reduction in sensory threshold has been shown quantitatively after cutaneous inflammation from superficial ultraviolet burns by Schumacher (1943) with the thermal radiation technique of Hardy and Oppel (1936). Studies by Wolff and Wolf (1948) and their other associates have shown in an exact quantitative manner the effect of local irritation of the nasal and gastric mucosa upon the threshold of responsiveness to pain. Conversely, the sensory threshold can be raised as much as 95 per cent by a 30 mg. dose of morphine (Hardy, Wolff, and Goodell, 1943).

B. PAIN CONDUCTION IN PERIPHERAL AND VISCERAL NERVES

A description of the sensory end organs and the types of fibres by which afferent impulses are conducted has been given in the preceding chapter. Elaborate receptors, such as those for tactile and proprioceptive sense, are connected to fibres of large diameter which have a rapid rate of conduction. These are probably not capable of transmitting pain.

The smaller myelinated and unmyelinated fibres, which transmit impulses at medium and very slow rates, terminate as free undifferentiated endings and are mainly concerned with painful sensation. Two kinds of conduction over these different types of fibres may be distinguished by the discriminating observer if he analyzes the sensation evoked by severe trauma to his toe. There is first a vivid flash of pain ascribed to the point of impact. Then, after an appreciable interval of a second or two, there follows a second, reverberating, aching pain that spreads up the leg. As expressed by Walshe (1942), the rapidly conducting fibres are responsible for the "brief rapidly developing pain of a prick, the other for the more slowly developing and longer lasting pain of injury." Pain from deep struc-

tures and viscera is usually of the latter variety. If sufficiently intense it often produces nausea, fall in blood pressure, syncope, and prostration. The former gives rise to reflex withdrawal and desire to escape by running away, while the latter, on the contrary, produces an urge to curl up in a quiet spot until the pain passes away.

In the experiments of Lewis (1942) the time interval between perception of slow and fast pain becomes greater the more distal the stimulation. He finds that the two fuse over the posterior surface of the body, and argues that this is because slow and fast conducting neurones are found only in the peripheral nerves and are not continued in the secondary neurones of the spinothalamic tract. On an anatomical basis, however, H. S. Gasser (personal communication) considers this most unlikely.

Lewis (1942) has made many interesting observations on the peculiarities of fast and slow pain. The first flash of pain which follows a sudden prick or thermal stimulus is a most distinct and clearly localized sensation The second is a more disagreeable and diffuse sensation, which tends to spread and to be more difficult to localize At a certain stage of asphyxia following application of a tourniquet, the rapidly-conducting nerve fibres are blocked, leaving only the disagreeable poorly-localized sensation transmitted by the more resistant slow fibres. In tabes dorsalis the fast-conducting fibres in the posterior roots may be injured selectively (Pochin, 1938). The resultant appreciation of pinprick, which reaches consciousness after a latent period of one to two seconds from the hand or foot, is distinctly more disagreeable and difficult to localize. The same is true of visceral and other forms of deep sensation.

Although the above clinical observations are not open to criticism, the thesis that the difference between fast and slow conduction explains variations in the types of sensation remains hypothetical. Weddell, Sinclair, and Feindel (1948) have recently investigated this problem. They find that the disagreeable quality of sensation in the period of sensory reinnervation and after prolonged application of a tourniquet is not due to a selective loss of the fast-conducting fibres, but to a reduction in the number of pain fibres. "Pain produced by the excitation of a single pain terminal and/or fibre is interpreted as being of a characteristically unpleasant quality, whereas stimulation of several overlapping terminals derived from different fibres, as in normal skin, gives rise to the familiar pain of everyday experience." Dysaesthesia occurs at a certain stage of tissue asphyxia or in the neuropathies when the cutaneous network of interweaving pain fibres has been reduced to a few isolated terminals.

C. SIMILARITY OF PAIN FROM DEEP STRUCTURES AND THE VISCERA

Although the classical teachings of Langley (1921) have emphasized the motor role of the autonomic nervous system, there is ample evidence that he was aware of the afferent supply from the viscera (summarized by Hinsey, 1935). He recognized that there are afferent fibres which accompany both parasympathetic and sympathetic pathways.*

Lewis's (1942) careful studies on himself, Kellgren, and others showed that there is no reason to differentiate between the conduction of pain from deep structures such as muscles, tendons, ligaments, joints, or periosteum on the one hand and from viscera such as the heart or intestines on the other. The majority of these impulses are conducted over slowly transmitting fibres of the "C" type, and the sensation is appreciated as a disagreeable prolonged ache which is difficult to describe and defies exact localization. Pain from either source may be referred to the corresponding segmental cutaneous dermatome.

The recent studies at Oxford of Feindel, Weddell, and Sinclair (1948) have given a clear-cut anatomical explanation for the peculiarities in perception of pain from superficial and deep structures. They cite previous experiments of Inman and Saunders (1944) on injection of irritant solutions into various deep somatic structures in human volunteers. They found the most sensitive to be periosteum, followed by ligaments, joints, tendon, fascia, and skeletal muscle. In their examination of the innervation of periosteum, fascia, and muscle, the Oxford anatomists found a corresponding variation in the concentration of pain receptors. Whereas in muscle the fine beaded terminals form a very loose meshwork and the individual endings are invariably isolated, in periosteum the meshwork is much more dense and there is interweaving and superimposition of adjacent terminals. The anatomical arrangement in fascia lies midway between. The high threshold and poor localization of sensation from the viscera must depend on these same factors, the accuracy of stimulus localization being a function of the density of innervation.

There is no longer any reason to insist on a fundamental difference between pain of visceral and of deep somatic origin. When Sir Thomas Lewis

---

*In Langley's (1903) own words: ". . . *all that seems to me possible at present towards arranging afferent fibres into autonomic and somatic divisions is to consider as afferent fibres those which give rise to reflexes in autonomic tissues, and which are incapable of directly giving rise to sensation, and to consider all other afferent fibres as somatic*" (Langley J.N.: The autonomic nervous system. *Brain*, London, 1903, 26 1-26, pp. 25-26)

injected hypertonic saline solution into the interspinous ligament* between the last cervical and first thoracic vertebrae of an individual with coronary disease, he evoked an intensely disagreeable sensation referred to the precordium and inner arm identical with a typical anginal attack. When others in his laboratory, sufferers from abdominal colic, were given similar injections beneath the fascia of the rectus abdominis muscle, the sensation evoked was identical with their recurrent complaints.

D. THEORIES OF VISCERAL PAIN

The evidence cited above for the similarity of visceral and deep somatic pain is of fundamental importance and calls for a complete reevaluation of current theories of visceral pain. By far the best known is Mackenzie's (1924) hypothesis that impulses from a diseased insensitive viscus bombard the posterior horn of grey matter and there set up an irritable focus, so that normal subthreshold cutaneous impulses break across the synapses to the secondary sensory neurones, which traverse the spinothalamic tract and give rise to the sensation of superficial pain (Fig. 20). Expressed in modern physiological terms, Mackenzie's concept of an irritable focus means that visceral stimuli facilitate somatic cutaneous impulses sufficiently to excite the production of a painful discharge in the secondary cutaneous neurones of the spinothalamic tract.

In recent years Livingston (1943) and Wolff and Hardy (1947) have reviewed the evidence of central spread of afferent impulses within the spinal cord through an "internuncial neurone pool." This explanation was first propounded by Sturge (1883), who described the mechanism as "an extension of commotion" within the grey matter of the posterior horn and compared this to the spread of a Jacksonian epileptic seizure over the cerebral cortex. The theory of referred segmental pain** was also used by James Ross of Manchester in 1888 to explain cutaneous reference, but Ross felt that visceral pain had a direct "splanchnic" component as well, consisting of a deep, poorly localized ache near the midline in the substernal,

---

*Weddell, Sinclair, Feindel, and Falconer (1948), who have repeated Lewis's experiments, checked the position of the injecting needle by x-ray and report that the sensation of referred pain is not evoked from the interspinous ligament, but develops when the injection escapes to the side and irritates a medial branch of the posterior primary division of the spinal nerve. In this case painful impulses so produced may well find themselves in possession of a single final pathway with others coming from deep structures such as the heart. It only needs to be assumed that the pain-receiving centre is incapable of distinguishing the ultimate source of these impulses to account for reference of deep pain to the body surface.

**According to Kinsella (1948) the first concept of heterotopic reference of pain should be accredited to John Hunter, who observed that "diseases of the liver are referred to the shoulder, of the testicles to the back, of the hip to the knee." Ross introduced the concept of segmental reference based on Darwin's studies of amphioxus.

epigastric, or abdominal region. Head, Rivers, and Sherren (1905) also arrived at the conclusion that the viscera are endowed with sensation of their own.*

It is unfortunate that because of Mackenzie's more prolific writings Ross's truer interpretation should have fallen into oblivion. If Mackenzie's

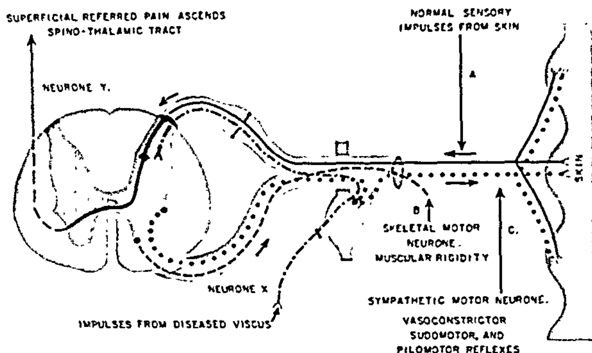


Fig 20 Mackenzie's concept of central misrepresentation of visceral pain: The "viscerocutaneous" theory.

Impulses from a diseased viscus propagated over Neurone X reach the posterior spinal horn via a white ramus communicans, spinal nerve, and its posterior root. On arrival in the posterior grey matter there is no synapse with a secondary spinothalamic neurone, but the visceral discharge sets up an "irritable focus." This lowers synaptic resistance between the cutaneous afferent (Neurone A) and its secondary fibre (Neurone Y) to such a degree that ordinarily subthreshold cutaneous impulses reach the thalamus and are appreciated as pain in the skin of the same spinal segment.

theory were the entire explanation, procaine infiltration of the cutaneous surface to which visceral pain is referred should relieve it. This is often not the case, as Lewis (1942) "failed to alter, in the least, anginal pain in an eminently suitable patient in whom the referred pain was focused over the sternum and could be provoked, with regularity and by a constant amount of effort, both before and after thoroughly anaesthetising the affected part of the body wall"

*"It will therefore be no adventurous guess to suppose that the system we have called protopathic in the skin is one with afferent fibres of the sympathetic as they supply the viscera. In both cases the sensation is badly localised, radiates widely, and is frequently referred to parts other than those stimulated." (Head, H., Rivers, W.H R. and Sherren, J.: The afferent nervous system from a new aspect. *Brain*, London, 1905, 28·99-115, p 114.)

Further evidence along this line has been given by a number of observers who have stimulated other deep structures and various viscera and found that pain was still present after infiltration of procaine into the cutaneous area of reference: viz., shoulder area on direct stimulation of phrenic nerve (Woollard, Roberts, and Carmichael, 1932); loin and groin with ureteral distension (McLellan and Goodell, 1943);* abdominal wall on distension of duodenum (Wolf, Wolff, and Goodell, 1947). However, there is no doubt that under suitable conditions pain or hyperalgesia referred to characteristic cutaneous areas can be relieved by local infiltration of procaine. This was demonstrated in the original observations of Weiss and Davis (1928) and also in more recent studies conducted at the Massachusetts General Hospital by C. M. Jones and W. P. Chapman (personal communication). These observers found that they could relieve the pain of experimental jejunal distension by procainizing the cutaneous areas of reference. However, if the stimulus was increased the pain always spread to the periphery of the insensitive area.

Cohen (1944) in his Lettsonian lectures has presented evidence, which seems irrefutable, that impulses coming in from the surface of the body may increase certain types of visceral pain, at least in their milder forms. He cites numerous examples in which peripheral lesions modified the radiation of anginal attacks In one individual with an amputated arm cardiac pain could be produced by pressure on a sensitive neuroma in the shoulder stump. Two other cases are also described in which brachial lesions caused striking changes in referred anginal pain. A man who had never experienced radiation of pain to the arm began to notice it in the elbow immediately after a fracture involving the joint. In a second patient who had never experienced right arm radiation, pain spread to a blistered area after the application of a vesicant plaster to the inner side of the elbow.

Theobald (1949), who has given an excellent review of this controversial subject, has added some pertinent evidence from faradic stimulation of the uterine cervix and fundus of healthy women in the course of routine pelvic examinations. The referred suprapubic pain from minimal stimuli was relieved by intracutaneous infiltration of physiological saline and that produced by a somewhat stronger current by 1 per cent procaine, but more intense stimulation always caused pain to break through within the anaesthetic zone.** Therefore it seems to us probable that subthreshold cutaneous

*In this excellent description of experimental production of ureteral pain these authors did not include the effect of procainizing the areas of cutaneous reference. They merely stated that they planned to do this. According to Wolff (personal communication) this has now been carried out without any change in appreciation of pain.

**More recently Abrams (1950) has reported that pain during the first stage of labour can be reduced and often entirely relieved by infiltration of the skin over the pubis and sacrum with procaine.

afferent impulses, which enter a common spinal segment into which an irritated viscus is also discharging, may be necessary to produce awareness of mild degrees of visceral pain. However, just as soon as noxious stimulation of the viscus becomes more intense the impulses will break through to the conscious level, even if the regional somatic innervation is blocked. Because of the paucity of nerve endings in the viscera and other deep structures, and also through lack of experience of conscious sensation arising from these areas, the individual is prone to misinterpret the source of such impulses. Ability to localize somatic sensation depends on the development of a cortical pattern of the body image in the parietal lobes. Perhaps through lack of experience with internal stimuli, no such visceral representation is ever built up by normal persons, although this appears to be possible to a limited degree in certain sufferers from chronic visceral disease (Szasz, 1949).

An alternative explanation to account for the central misrepresentation of painful impulses which reach the spinal cord from visceral or deep somatic structures and are erroneously referred to the skin has been proposed by Ruch (1949). This accounts for most of the phenomena of referred pain on the basis of convergence of visceral and cutaneous afferents on the same spinothalamic neurones shared in common by both sets of fibres (Fig. 21). He states that, as there are many more pain fibres in the posterior roots than axones in the spinothalamic tracts, both a visceral and a cutaneous pain fibre may converge on many of the secondary neurone cells in the posterior horn. On most occasions "when these particular spinothalamic neurons have been activated, stimulation of the body surface was responsible, as verified by other senses. Thus when impulses of visceral origin reach the cerebral cortex, the interpretation is made which experience has built up—that of a pain arising from cutaneous pain neurons."

On the basis of phylogenetic data on the general anatomical plan of the peripheral nervous system, Sinclair, Weddell, and Feindel (1948) have recently formulated a theory which may give a simpler explanation to the peculiar phenomena of misinterpretation of the source of painful stimuli and hyperalgesia. This depends on the anatomical concept of branching in sensory axones. The existence of branched axones with one terminal supplying the gut and the other the skin was demonstrated in fishes by Wernøe (1925); that a single fibre may branch to several widely separated areas of skin was shown by Adrian, Cattell, and Hoaglund (1931) in frogs. Such an arrangement has also been pictured by Dogiel (1896) in mammals. We feel that this concept of sensory axones with branches to visceral as well as somatic structures can at present be regarded only as an intriguing speculation which requires anatomical proof in man. It is to be hoped that the anatomists at Oxford, who have contributed so much to our understanding

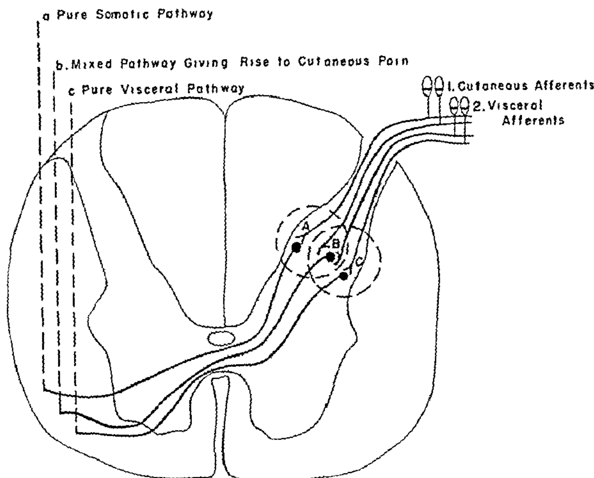


Fig 21 Ruch's concept of central misrepresentation of visceral pain:
"Convergence-projection mechanism of referred visceral and somatic pain based upon Sherrington's neuron-pool concept. A, B, C represent a neuron pool consisting of all the spinothalamic tract fibres originating in one segment of the spinal cord A is the field of neurons having connections only with afferent fibres from cutaneous sense organs B is the field of overlap constituted by neurons which receive impulses from *both* visceral and cutaneous afferents, and impulses in b will give rise to pain referred to the skin C are those neurons of the pool which connect only with afferent fibres from the visceral cavities, and give rise to unreferred or true splanchnic pain. Only one neuron in each category is represented . . . a, b, c, are fibres in the spinothalamic tract having cell bodies in fields A, B, and C respectively."
Drawing adapted and legend quoted from Ruch in Fulton's *Textbook of Physiology*, 1946. Courtesy, W B Saunders Co, Philadelphia

of sensory innervation, will be able to furnish this. Such an arrangement could explain "not only the feasibility of impulses arising from the viscera being referred to somatic structures, but also the fact that such referred pain may sometimes be felt in the skin, or in the deeper structures, or in both."

With this arrangement as a premise Sinclair *et al.* have postulated that "there are two main mechanisms at work; the first of these is the misinterpretation by the central receiving apparatus of the source of the painful impulses (Fig. 22A), and the second is the production in the periphery, as

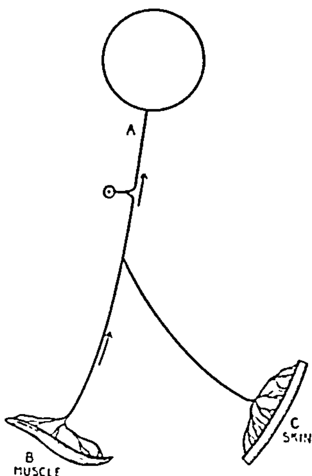
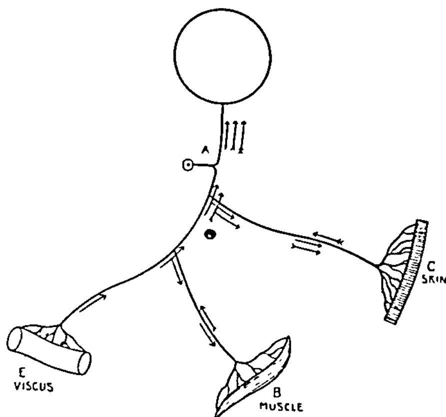


Fig. 22. Sinclair, Weddell, and Feindel's concept of central misrepresentation of visceral pain: The "branched-axon" theory

A (*upper*). "Impulses passing up the common stem A of the branched axon from the muscle B are interpreted by the receiving centre as coming from the area of skin C."

B (*lower*). "Multiple reference from a viscus. The arrows indicate the pathways traversed by the impulses set in train from a focus in the viscus E. Secondary pathways in unbranched axons have been omitted for the sake of clarity. (The different flighting of the arrows indicates the different origins of the impulses they represent.)"

Figures and legends from Sinclair, Weddell, and Feindel. *Brain*, 1948, by permission of the editor



a result of antidromic impulses, of metabolites which at first stimulate the nerve endings there and later damage them (Fig. 22B). It is probable that the operation of the first of these mechanisms gives rise chiefly to referred *pain*, while the chief result of the operation of the second is referred *tenderness*. . ."* According to this assumption, referred pain in the early stages must be an illusion, the result of central misrepresentation, whereas in the later stages the chemical factor becomes more important, with the result that the sensation of hyperalgesia persists long after the removal of the original cause. In the first instance procainization of the skin would not affect the referred sensation, whereas cutaneous hyperaesthesia or muscle tenderness would be relieved.

Wolff and Hardy (1947), who have studied referred hyperalgesia in an extensive series of experiments on themselves, question the explanation of this phenomenon on the basis of a painful metabolite produced by antidromic impulses and prefer the theory of a central excitatory state in the spinal cord evoked by the barrage of afferent nervous stimuli. These investigators, like Livingston, postulate a network of internuncial neurones in the spinal grey matter which are intercalated amongst "the neurones mediating noxious impulses from visceral, deep somatic, and cutaneous tissues." Under these conditions intense bombardment of the central mechanism from any of these sources may result in a spread of the disturbance to neighbouring spinal segments. In experiments reported in which the fourth finger was placed in ice-water, pain gradually spread to the contiguous digits. Procainization of the digital nerves in the secondarily involved fifth finger did not eliminate the pain. This should be the case if a metabolite were produced under the stimulus of antidromic conduction. Furthermore, the pain does not appear to have developed quickly enough in the other fingers to be accounted for on the theory of misrepresentation through branching of sensory fibres. One is therefore forced to the conclusion that the extension of pain under these circumstances must be caused by spread of the central excitatory state within the posterior horn of the spinal cord.

The reader who wishes to go into further details concerning the critical data on which the theories of referred pain are based cannot do better than refer to Wolff and Hardy's article, "On the nature of pain" (1947). They have divided the neurophysiological mechanisms that underlie the perception of pain from deep tissues into three categories:

> "1. *True visceral and deep somatic pain.* Such pain is felt at the site of primary stimulation and may or may not be associated with referred pain It is eliminated by infiltration of procaine into the site of noxious stimula-

---

*Sinclair, D.C., Weddell, G. and Feindel, W.H.. Referred pain and associated phenomena. *Brain*, London, 1948, *71*:184-211, p. 201.

tion or by blocking its afferent nerves, but it is not altered by infiltration of procaine into other structures supplied by the same or adjacent neural segments.

"2. *Referred pain.* Such pain may occur in addition to or in the absence of the true visceral and deep somatic pain described above. It is experienced at a site other than that of stimulation but in tissues supplied by the same or adjacent neural segments. It may occur either with or without associated hyperalgesia and hyperesthesia.

"a. *Without superficial and/or deep hyperalgesia.* In this case pain depends only on the central effects of the spread of excitation of the original noxious impulses to the same and adjacent segments of the cord whence they are relayed to higher centres for perception and interpretation. Injection of procaine into superficial or deep regions of referred pain does not reduce the intensity of pain due to this mechanism.

"b. *With superficial and/or deep hyperalgesia.* Referred pain may be accentuated in intensity by virtue of the effects of ordinarily non-noxious stimuli from zones of reference. Impulses from such sources, normally inadequate to produce pain, may do so upon reaching the cord in a segment involved in central spread of excitation. Procaine injected into superficial or deep hyperalgesic structures will abolish this element of the referred pain phenomenon, resulting in more or less reduction of the subject's discomfort, depending on the amount of hyperalgesia.

"3. *Pains due to secondary skeletal muscular contractions which provide a fresh source of noxious impulses.* Pain may result from secondary effects of the central spread of excitation on the effector structures, including painful contractions of skeletal muscles. Such disturbances may be wide spread and the pains may be experienced in situations remote from the original source of noxious stimuli. Local infiltration of the contracted muscles with procaine abolishes this type of pain by disrupting its peripheral mechanism."*

As Wolff and Hardy's experiments have so clearly shown, the most effective method of interrupting visceral pain is to interrupt the splanchnic pathways over which the primary impulses reach the central nervous system.

Surgeons who have studied the problem of visceral sensitivity from the more direct aspect of its interruption by denervation have found that after splanchnicectomy no pain can be induced by acute duodenal distension (Bentley and Smithwick, 1940) or by a great variety of stimuli applied to the gall bladder and various levels of the intestinal tract (Ray and Neill, 1947). The most convincing proof of direct conduction of visceral pain in man has recently been supplied by Bentley (1948A). In the course of laparotomies for chronic peptic ulcers under abdominal field block anaes-

*Wolff, H.G. and Hardy, J D.: On the nature of pain. *Physiol. Rev.*, 1947, 27:167-199, pp. 191-192, courtesy of American Physiological Society, Inc., Washington, D.C.

thesia he observed that the stomach or duodenal wall involved in the ulcer was directly sensitive to pressure, to needle-prick, and to chemical stimulation.* Despite complete anaesthesia of the anterior abdominal wall, the inflamed viscus itself was sensitive and the pain disappeared only when the splanchnic nerves were blocked with procaine.

In animal experiments Davis, Hart, and Crain (1929) found that pain produced by experimental distension of the gall bladder, although relieved by splanchnicectomy or posterior rhizotomy, is not interrputed by cutting the corresponding intercostal nerves and the ensuing anaesthesia of the lower thoracic and abdominal parietes. White, Garrey, and Atkins (1933) found the same to be true of experimental cardiac pain in dogs, which is relieved by resection of the four superior thoracic ganglia or upper five pairs of posterior spinal roots, but is in no wise altered if the corresponding intercostal nerves are severed distal to the inflow of the sympathetic white rami.

Morley (1931) has more recently returned to a recognition of the concept of true visceral or "splanchnic" sensation, but ascribes referred pain to local inflammatory irritation of the sensitive area of the parietal peritoneum. In this way an attack of acute appendicitis first results in mid-abdominal colicky pain, transmitted directly over the splanchnic nerves during the period of distension and stretching of the appendiceal wall. Later, as inflammation spreads from the organ itself to the more sensitive parietal peritoneum, it evokes pain in the right lower quadrant carried over the lower intercostal nerves. Morley's hypothesis of a "peritoneo-cutaneous reflex" undoubtedly gives a valid explanation for certain types of referred pain in visceral disease of inflammatory origin, but it fails to account for pain referred to the surface of the body in non-inflammatory conditions such as angina pectoris. There is no cogent reason for assuming that such a deep-lying structure as the heart, which in the course of an anginal attack neither comes in contact with sensitive parietal pleura nor undergoes any inflammatory change, can give rise to referred pain by such a mechanism. Despite Morley's helpful suggestion, we must still explain many forms of pain referred to distant areas lateral to the midline either on the basis of central misrepresentation of the source or to a viscerocutaneous reflex. After weighing the evidence we have come to the conclusion that it is not possible to discard the theory of the potentiation of visceral pain by cutaneous impulses altogether, but it is certain that this mechanism is of far less impor-

---

*Sensitivity of peptic ulcers to direct manipulation was first recorded by Dragstedt and Palmer (1932) and further observations were reported by Kinsella (1948) on similar responses from the inflamed appendix. The fact that normal gastric mucosa can be made sensitive to tactile stimulation after local irritation with mustard has also been shown by Wolf and Wolff (1943).

tance than was formerly supposed. It has no practical application to securing permanent relief of pain in visceral disease.

On the basis of evidence reviewed above it is obvious that there are no characteristic features of visceral pain that set it apart from pain arising in deep somatic structures. Even in such a common experience as a toothache pain cannot often be localized in the infected tooth and may even spread to other divisions of the trigeminal nerve. The phenomena of referred pain are thus not limited exclusively to the internal organs, and the very imperfect localization of visceral pain is not related to any unique peculiarity of the viscerosensory innervation.

E. THE VISCEROSENSORY NERVES. CENTRAL TRANSMISSION OF VISCERAL PAIN

The outstanding descriptions of visceral innervation are to be found in Hovelacque's (1927) monograph and the anatomical papers of Mitchell (1935A and B, 1938A and B, 1940) which have recently been incorporated in an outstanding volume (1953). Even the most painstaking dissections, however, can give us no accurate concept of the relative importance of these structures in the conduction of pain. This knowledge can only be obtained by stimulating the nerves from each viscus at operation under local anaesthesia or by observing the effectiveness of various neurectomies on subsequent testing. In this way surgeons have been able to gain a fairly satisfactory working knowledge of the important afferent trunks from each viscus. At a symposium on pain before the Association for Research in Nervous and Mental Disease one of us (White, 1943) summarized this subject in a series of anatomical diagrams. These are reproduced in Figures 127, 130, 131, 133, and 134. From our experience with viscerosensory denervation in several hundred patients it is our belief that the pathways illustrated are correct as far as they go. Further details concerning regional sensory innervation of specific viscera will be found in Chapters XI, XIX, and XX, which describe the surgical technique of sympathectomy and the clinical results of applying these principles.

The vagus, below the level of the superior laryngeal nerve and its tracheal and oesophageal branches, probably carries no fibres capable of transmitting pain. This has been substantiated experimentally by B. Cannon (1933) in cats by stimulation with previously placed electrodes and by Grimson *et al.* (1947) in man in the course of operations under spinal anaesthesia. Recent and as yet unpublished observations made by Mr. P. G. McEvedy in Manchester, England, and reported to us by Mr. Antony Jefferson are, however, at variance with these findings. In operating under abdominal "field block" anaesthesia and with the splanchnic trunks infiltrated between the aorta and vena cava at the level of the first lumbar ver-

tebra, McEvedy has occasionally observed sharp, painful responses when the vagi are cut or crushed. Jefferson states that "from seeing some 60 vagotomies I would say that we elicit pain in the posterior vagus in one patient out of four or five. Much more rarely we elicit pain from the anterior vagus. It appears usually to be sited in the back at approximately the level of T9 or T10." This of course is the area to which pain has often been referred when we have stimulated the major splanchnic nerves, and it appears quite likely that the prevertebral block may have missed a few of their fibres in the patients who felt pain, or that this may have been transmitted by higher splanchnic fibres, which often join the vagi above the diaphragm. Either eventuality would explain why Grimson, when he stimulated the abdominal vagi under spinal anaesthesia, was not able to elicit any response. It has long been known that central stimulation of the vagi below the midthoracic level may produce a sense of nausea, and that both vagi as well as splanchnic trunks must be divided in dogs to prevent the vomiting of peritonitis (Walton, Moore, and Graham, 1931).

In contrast to the abdominal vagi, the lower cervical and upper thoracic sympathetic rami running to the heart, the splanchnic trunks to the liver, pancreas, and intestines, and the nerves in the renal pedicle and the superior hypogastric plexus, all carry a rich supply of pain fibres. The same is true of the parasympathetic outflow to the pelvic viscera from the second, third, and fourth sacral segments. Their presence can be proved by proper physiological stimulation of these viscera, and by the fact that pain is consistently eliminated after interruption of these pathways.

The existence of pain-conducting fibres in the cardiac rami and splanchnic visceral trunks has been clearly demonstrated by stimulation on the conscious patient under local anaesthesia. Leriche (1949) in the course of a stellate ganglionectomy for angina pectoris witnessed the onset of a severe attack on freeing up the ganglion, which was immediately controlled by its infiltration with procaine. Preliminary injection of the exposed vagus had had no effect. Both Leriche (1937B) and Adson (1935A) have observed the response to stimulation of the major splanchnic nerve under spinal anaesthesia Leriche's patient claimed that he experienced pain in the region of his heart.* This has not been our experience in numerous cases where the central end of the divided major splanchnic nerve was stimulated electrically in the course of operations for hypertension under local anaesthesia ** These patients complained of intense pain experienced in the upper

*Absence of abdominal reference was doubtless due to the fact that the posterior thoracic spinal roots below T7 were blocked by the spinal anaesthetic

**Supplementary light pentothal and nitrous oxide were administered until the exposure of the splanchnic trunks had been completed, but the patient was allowed to awaken prior to testing. When this is done, the patient has little, if any, remembrance of discomfort afterwards

abdomen on the side of stimulation. There was no detectable latent period and the sensory threshold was no different from that of the twelfth intercostal nerve. Sensations of approximately similar intensity resulted from stimulating each nerve by a current at 1 volt with a frequency of 30 cycles, in the form of square waves of 1 millisecond duration.

While the viscerosensory nerves accompany the visceral arteries, few if any afferent axones accompany the blood vessels beyond the thoracic outlet or below Poupart's ligament. Some may claim that the sensory innervation of certain cephalic structures should be classified as visceral in origin, as these are partly supplied by the vagus. It must be pointed out, however, that vagal afferent axones which supply the larynx, pharynx, and ear belong to the somatic system. Their ganglion cells lie in the ganglion nodosum and their central fibres mediating pain probably join those of the descending tract of the trigeminal nerve. The remaining sensitive structures within the skull are supplied by other cranial nerves, viz., trigeminal, nervus intermedius, and glossopharyngeal—all likewise part of the somatic system. We have found less convincing evidence to support transmission of pain from intracranial structures or the face along the carotid or vertebral arteries, or over the cervical sympathetic. Davis and Pollock (1932) have not been able to elicit any pain from stimulation of the superior cervical ganglion in cats (see p. 614) if the trigeminal and upper spinal posterior roots have been previously cut. In order to explain the presence of painful responses on stimulation of this ganglion they therefore suggested that the responses observed are due to impulses evoked in the efferent sympathetic fibres which, upon reaching the periphery, in some way affect pain receptors in the cranial and spinal nerves. Neither these investigators nor Cleveland (1932) have been able to evoke any evidence of pain in cats on stimulation of the trunk proximally after it has been severed below the superior cervical ganglion. Furthermore, Ranson and Billingsley (1918) were unable to find either physiological or histological evidence for the presence of afferent fibres above the stellate ganglion. We should like to point out, however, that the inflow of afferent fibres to the spinal cord does not necessarily coincide with the outflow of the sympathetic efferents, which are not present rostral to the stellate ganglion. This arrangement has always been assumed, but on p. 85 we present evidence that it may not be the case in man. If there are a few sensory fibres in the cervical sympathetic rami passing to the sympathetic chain, these will not necessarily degenerate in an ascending direction after section of this structure. This is the anatomical evidence on which Ranson and Billingsley have based their argument.

Reports on stimulation of the cervical sympathetic pathways in man are few. Frazier (1925A) has found that electrical stimulation of "the cervical sympathetic ganglion or the periarterial sympathetic plexus of the common

carotid artery" frequently causes pain within the zone of the trigeminal distribution. Leriche (1949) also states that mechanical or electrical stimulation of the superior cervical ganglion, of the first two cervical rami communicantes, or of the sympathetic chain down to the middle cervical ganglion causes severe pain in the teeth and bone of the lower jaw. Stimulation of the adventitia at the carotid bulb or on the common carotid artery produces a similar but less intense pain. Somewhat along the line of Davis and Pollock, he explains such pain on the basis of excitation of vasomotor fibres in the trigeminal sphere, rather than attributing it to direct participation by sympathetic fibres in the innervation of the jaw and teeth. He has found that stimulation of the chain lower down causes pain in the precordium and arm.

Foerster, Altenburger, and Kroll (1929), on the other hand, not only stated that the cervical sympathetic trunk contains pain fibres, but they also thought that these enter the spinal nerves and spinal cord via white rami communicantes, because they were able to evoke severe ipsilateral pain in the head upon stimulation of the caudal end of the sympathetic trunk divided below the superior cervical ganglion

Our own experiences with stimulation of the superior cervical sympathetic ganglion and related nerves have led to highly variable responses in different individuals with respect to pain. Only those patients are included in our analysis in whom the exposure was carried out with sufficient finesse and without infiltration of procaine at or behind the carotid vessels, so that a stimulus to the upper trunk or ganglion yielded prompt pupillary dilatation. When pain occurred it was always ipsilateral In five of 10 such patients there was pain referred to face, jaw, ear, or head when the superior cervical ganglion or the trunk below it was stimulated. In the other five patients there was no such facial or cephalic pain. One of these had no pain; another's pain was referred to the chest; another had pins-and-needles in the neck and down the arm into the hand; the fourth had pain in the neck only; and the fifth experienced chiefly numbness and a "crawling sensation" from the neck down the lateral aspect of the arm into the first three fingers with extension on some stimuli onto the side of the head and into the eye. In only three of 13 effective stimuli did he have any pain which was referred to the side of the neck. Several other patients described a numbness at threshold voltages which became a pain 1 to 3 volts higher. In four of the five patients in whom we elicited pain in the face or head we divided the trunk just below the superior ganglion and in none of these did stimulation of the caudal stump then cause the more rostral pain that Foerster found. Moreover the responses of pain were not obtained from all portions of the trunk or ganglion when small bipolar electrodes with points less than 1 mm. apart were used to explore the surfaces, whereas peripheral nerves such as

those in the cervical plexus almost invariably yield a response of pain no matter where such an electrical stimulus is applied.

In one patient (*Zelda K.*, MGH U-171870) we dissected free three small twigs passing from the superior ganglion ventromedially toward the pharynx, i.e., not rami communicantes. Stimulation of the two uppermost of these caused pain "deep in the throat," whereas no pain ensued from the lowest twig. Stimulation of the ganglionic end of each of the two upper twigs reproduced the response of pain when the twig was intact, whereas stimulation of the end passing into the tissues caused no pain. This patient was also of special interest because she had a complete facial paralysis persisting two years after the removal of an acoustic neuroma plus a trigeminal anaesthesia after subsequent total trigeminal neurotomy. Yet stimulation of her superior cervical ganglion at 2 volts repeatedly caused severe pain inside the mouth.

In our own earlier consideration of pain fibres travelling with the sympathetic nerves we have been prone to forget that we lack evidence regarding the location of the cell bodies from which these axones arise. Kölliker (1896, p. 858) and Langley (1903) have described as sensory fibres some white myelinated fibres presumed to pass without interruption from their cell bodies in the spinal ganglia via splanchnic nerves to the viscera. We know of no evidence as to the location of the cell bodies for the many unmyelinated fibres in the sympathetic nerves. From the arrangement in the somatic nerves it is reasonable to assume that at least as many pain fibres in the sympathetic nerves will be unmyelinated as will be myelinated. Furthermore, while we have evidence that the motor outflow from the central nervous system into the sympathetic trunks is confined to the C8 to L2 zone of outflow of the white rami communicantes, we have evidence that the sensory inflow is not confined to these white rami. Indeed, we have five patients in our series in whom stimulus of each member of a pair of rami communicantes evoked pain. In a sixth patient, Zelda K., stimulus to the grey rami connecting the superior cervical ganglion to the IIIrd and IVth cervical nerves caused pain in the neck near the ear (ramus to C3) or in front of the ear (ramus to C4). When the latter twig was divided the response persisted only from the cut end toward the somatic nerve, not from the ganglionic end. Details of some of the responses from the paired rami follow:

Harry T. (MGH U-717146BM), with abdominal carcinoma, had pain referred to the umbilical region whenever either ramus communicans from T10 sympathetic ganglion was stimulated (the rami labelled *f* and *g* in Fig 102, Chap. XI). Mava S. (NECH #48,833), a woman with malignant hypertension, had the acute pain deep in the right lumbar region above the iliac crest no matter which ramus communicans from T12 was stimulated. 0.05 volts sufficed to produce this and the same response was obtained from

carotid artery" frequently causes pain within the zone of the trigeminal distribution. Leriche (1949) also states that mechanical or electrical stimulation of the superior cervical ganglion, of the first two cervical rami communicantes, or of the sympathetic chain down to the middle cervical ganglion causes severe pain in the teeth and bone of the lower jaw. Stimulation of the adventitia at the carotid bulb or on the common carotid artery produces a similar but less intense pain. Somewhat along the line of Davis and Pollock, he explains such pain on the basis of excitation of vasomotor fibres in the trigeminal sphere, rather than attributing it to direct participation by sympathetic fibres in the innervation of the jaw and teeth. He has found that stimulation of the chain lower down causes pain in the precordium and arm.

Foerster, Altenburger, and Kroll (1929), on the other hand, not only stated that the cervical sympathetic trunk contains pain fibres, but they also thought that these enter the spinal nerves and spinal cord via white rami communicantes, because they were able to evoke severe ipsilateral pain in the head upon stimulation of the caudal end of the sympathetic trunk divided below the superior cervical ganglion.

Our own experiences with stimulation of the superior cervical sympathetic ganglion and related nerves have led to highly variable responses in different individuals with respect to pain. Only those patients are included in our analysis in whom the exposure was carried out with sufficient finesse and without infiltration of procaine at or behind the carotid vessels, so that a stimulus to the upper trunk or ganglion yielded prompt pupillary dilatation When pain occurred it was always ipsilateral. In five of 10 such patients there was pain referred to face, jaw, ear, or head when the superior cervical ganglion or the trunk below it was stimulated. In the other five patients there was no such facial or cephalic pain. One of these had no pain; another's pain was referred to the chest, another had pins-and-needles in the neck and down the arm into the hand, the fourth had pain in the neck only, and the fifth experienced chiefly numbness and a "crawling sensation" from the neck down the lateral aspect of the arm into the first three fingers with extension on some stimuli onto the side of the head and into the eye In only three of 13 effective stimuli did he have any pain which was referred to the side of the neck. Several other patients described a numbness at threshold voltages which became a pain 1 to 3 volts higher. In four of the five patients in whom we elicited pain in the face or head we divided the trunk just below the superior ganglion and in none of these did stimulation of the caudal stump then cause the more rostral pain that Foerster found. Moreover the responses of pain were not obtained from all portions of the trunk or ganglion when small bipolar electrodes with points less than 1 mm. apart were used to explore the surfaces, whereas peripheral nerves such as

if present in the peripheral sympathetic system and distributed in similar fashion to the motor fibres, after reaching the chain of paravertebral ganglia would enter the posterior root system several segments below the somatic arm inflow, or at a higher level in the case of the leg. They could reach the paravertebral chain after a temporary course in the peripheral nerve trunks or by ascending in the periarterial plexus. Although it is now recognized that visceral afferents pursue a course along such vessels as the coronary, hepatic, renal, and mesenteric arteries, this is not generally conceded to be the arrangement in the extremities distal to the subclavian and iliac arteries.

While we know of no direct anatomical evidence that pain impulses from the peripheral arteries reach the spinal cord by way of the sympathetic trunks, the existence of such accessory pathways has nevertheless been claimed by Leriche (1919), Foerster (1927A), Kuntz and Saccomanno (1942), Threadgill (1947), Slaughter (1938), and others. Much of this evidence is open to criticism. Foerster, for example, found that a patient with division of the lower three roots of his brachial plexus and complete anaesthesia of the little and ring fingers could feel pain on direct stimulation of a digital artery within the anaesthetic zone. There is no reason why sensory filaments should not spread from an artery within the territory of the ulnar to the median nerve along the deep palmar arch. Foerster, Altenburger, and Kroll (1929) cite another case in which all the fibres entering the brachial plexus from C4 down through the intercostohumeral nerve had been divided distal to the entrance of the rami communicantes. A clamp applied to the otherwise anaesthetic paralyzed fingers caused dull pain which the authors ascribed to conduction via sympathetic nerves on arteries up to the sympathetic trunk. They supplied no positive evidence that the stimulation of such nerves would reproduce the pain. In the patient reported by Slaughter with confirmed transection of the conus at the level of the first lumbar vertebra, the burning pain in the lower extremities was relieved by lumbar sympathetic ganglionectomy. However, it is still possible that the beneficial effect of sympathectomy in this case may be related to interruption of efferent impulses (see p. 362) and that pain set up in the lower extremities could still have reached the cord over intact lumbar roots entering the cord above the point of injury. In World War II lumbar sympathectomy was used on numerous occasions (Freeman and Heimburger, 1947) in the hope of relieving burning pain in paraplegia, but the results were nearly always disappointing. Conclusions based on animal experiments, such as have been reported by Kuntz and Saccomanno (1942), by Threadgill (1947), and by Freeman, Shumacker, and Radigan (1950), have never been thoroughly convincing in problems of human pain. Furthermore Holden (1948), who has attempted to confirm these experi-

the central cut end of each ramus, whereas no sensation followed even 5 volts to its peripheral end. Likewise from each ramus of T11 ganglion a "heavy ache" was elicited deep in the right lumbar region, but somewhat higher than the pain arising from stimulation of the T12 rami. This required 5 volts for each member of the pair and the same response at the same voltage was obtained from the central cut end of each pair. Also in the case of *T. P.* (Providence V. A Hospital #10660), who had post-traumatic causalgia in a lower limb, stimulus to each ramus communicans from L3 ganglion caused severe pain in the back in the renal region.

We have not found it possible in man to distinguish *in vivo* between the grey and white ramus in any given pair. If then any of the grey or white rami may conduct pain impulses from the sympathetic trunk toward the spinal cord, there is no necessity for assuming that a stimulus applied to the superior cervical sympathetic ganglion must pass caudally in the cervical sympathetic trunk in order to gain direct access to the spinal cord. Furthermore, only stimulation of the ganglionic end of cut peripheral branches of the superior cervical ganglion in Zelda K. reproduced the effect of stimulation of that branch when intact. This fact controverts the contention that it must be efferent impulses passing to the periphery which set up pain in receptors there. More evidence against this contention is supplied by the production of unilateral pain in the mouth of the same patient upon sympathetic stimulation despite the trigeminal and facial denervation of this region, eliminating the central connections of the usual somatic pain receptors.

The observations just recorded force us tentatively to advance the hypothesis that pain fibres may travel in the cervical sympathetics of some people. They also lead us to advance the more revolutionary concept that the afferent fibres travelling with the sympathetic nerves are not necessarily bound to the rigid portals of entrance to the central nervous system which govern the exit of efferent sympathetic fibres—i.e., white rami from C8 to L2—but that these afferent fibres may reach the spinal cord via grey or white rami throughout the full length of the sympathetic trunk. Attempted clinical applications of this concept have not been particularly fruitful, however, as we describe in detail in Chapter XVI under the heading of atypical facial neuralgia

The question of whether pain from the arm or leg can reach the spinal cord by passing through the chain of sympathetic ganglia is still under debate. If this were so it would afford an explanation for the perplexing problem of relief after sympathectomy in causalgia and the allied reflex sympathetic dystrophies. An accessory afferent pathway of this sort would also explain why section of all the posterior (and even the anterior) roots of the brachial plexus has failed so consistently to relieve pain of amputation stump neuralgia and phantom limb. Afferent axones,

the electrode was applied or the chain compressed. Nevertheless the throbbing, aching pain in the ankle and foot ceased after sympathectomy.

In the second patient (T. P., Providence V. A. Hospital #10660), electrical stimulation of various parts of the lumbar sympathetic ganglia and nerves was carried out at a similar operation by Dr. Hannibal Hamlin. That of L2 ganglion caused pain or at times a pressure and "full feeling" either in the ipsilateral groin, deep in the abdomen below the umbilicus, or around the kidney. That of L3 ganglion caused sharp or burning pain deep in the ipsilateral back. Despite thorough coverage of both dorsal and ventral aspects of these two ganglia, of several rami toward the periphery therefrom, and of both rami communicantes from L3 ganglion, no pain in the lower limb was elicited. Yet here too the clinical pain in the lower limb stopped after sympathectomy.

Simeone (see discussion of paper by Freeman, Shumacker, and Radigan, 1950), who has placed pull-out electrodes on the lumbar ganglia in the course of a number of general surgical procedures in the Massachusetts General Hospital and thereby stimulated the sympathetic chain after the patient's recovery from anaesthesia, has likewise failed to evoke any reference of pain outside the abdomen.

There is, however, a recent report by Echlin (1949) that differs from our observations. In the course of removing the lumbar chain in a patient with a painful mid-thigh phantom under local anaesthesia, he stimulated in the region of its third ganglion both electrically and mechanically. Stimulation gave rise repeatedly to severe pain shooting down from the hip to the phantom toes. There was mild pain of similar nature on stimulating the severed end of the chain distally, but it was unbearably intense each time the proximal stump was tested. The result of this sympathectomy has been eminently satisfactory and has continued so for many months. We are unable to explain this single report so completely at variance with our own observations. It is of course possible that in a few exceptional individuals pain-conducting fibres may ascend in the peripheral sympathetic plexuses from the extremities, although such is not the case in the great majority.

Although there have been numerous well-documented reports by Leriche (1949), Fontaine and Herrmann (1933), and Homans (1940) of relief of causalgia, painful post-traumatic osteoporosis, and other related conditions following periarterial sympathectomy, it is our opinion that this has resulted not from interruption of afferent nerves ascending along the arteries but from a non-specific effect of the operation. A number of years ago one of us (J.C.W.) observed that there is a transitory rise in temperature of all the extremities which results alike after periarterial sympathectomy or after such non-specific operations as herniorrhaphy or

ments in the laboratories of Western Reserve University, has been unable to do so. Hinsey (personal communication, 1951) likewise has found "no evidence, either clinical or experimental, which will stand critical analysis, to support the view that pain impulses from the extremities reach the spinal cord by way of the sympathetic ganglia."

We have recently been able to put this possibility of accessory afferent pathways from the limbs through the sympathetic ganglia to what would appear to be a conclusive test in human subjects:

Ralph T., MGH U-382923 BM, 56. This intelligent athletic individual had suffered a traumatic low thigh amputation in 1918. Severe amputation stump neuralgia had developed in 1936. Re-exploration of the stump and neuroma excision elsewhere had had no effect on his pain, and there were no trigger areas of tenderness to suggest recurrence of sensitive neuromata. His stump neuralgia was effectively relieved by a cordotomy performed by Dr. W. J. Mixter in 1945. The level of analgesia extended only to the umbilicus. He returned to his work as a manufacturer of golf clubs and continued to play 18 holes of golf in under 80 Gradually, however, the analgesic level receded and his pain recurred in less severe form. He had been told by a number of other surgeons that his residual discomfort would be relieved by sympathectomy. This we denied emphatically, especially as *he had experienced no improvement following an effective* paravertebral procaine injection of his lumbar ganglia. He did not want to accept our recommendation for a secondary higher cordotomy and insisted upon a trial of lumbar ganglionectomy. To this we finally agreed, with the proviso that it be done under regional procaine anaesthesia to permit testing for the presence of afferent fibres from his leg in the lumbar chain by direct stimulation The patient was completely cooperative and interested in the result of this experiment on himself. Accordingly on 11/25/47 the lumbar chain was exposed from crus of diaphragm to the common iliac artery. Although its mechanical stimulation invariably produced diffuse pain referred to the lower abdomen and pelvis, we were never able to elicit any sensation referred to his painful stump. Similarly, resection of the chain from L1 to L3 inclusive had no effect on the neuralgia *

Two other confirmative observations have been recently made:

The first of these was in a case of post-traumatic pain in the ankle with patchy osteoporosis (Mary K. M G.H. 699338). Before resecting the lumbar chain we allowed the woman to awaken and stimulated the second and third lumbar ganglia. This evoked no sensation referred to the leg or foot, but very definite pain in the upper abdomen and left flank each time

*Walker and Nulsen (1948), who have stimulated the upper thoracic sympathetic ganglia in man, have likewise reached the conclusion that there is no central conduction of pain from the extremities over this route (see p 363).

fibres supplying the two types of tissues are alike; and the fact that those from somatic structures at first use the channel of the spinal nerve, and that those from visceral structures at first use the channel of the anatomical sympathetic system before entering the posterior roots is really immaterial."*

In their central course the painful impulses from the viscera enter the spinal cord over its posterior roots and can be interrupted by rhizotomy. This method has found practical application for the relief of angina pectoris and painful aneurysms of the aorta (see pp. 639, 647), but in general it is simpler to cut the more readily accessible splanchnic nerves or to resect the paravertebral ganglia through which the sensory axones pass before entering the spinal nerves.

Once painful impulses have reached the posterior horn of the spinal cord, they appear to cross completely to the opposite anterolateral column and ascend to the thalamus with the somatic afferent pathway. We realize that Davis, Hart, and Crain (1929) have described a bilateral pathway with frequent cross-overs, and that Ranson and Clark (1947) have stated that bilateral cordotomy is required to abolish visceral pain in man. Nevertheless, in experimental observations after anterolateral cordotomy we have found that pain of renal or intestinal origin is no longer felt on the analgesic side of the body. Whether it is actually transmitted within the spinothalamic tract or runs over some other afferent column in the anterolateral quadrant we are not prepared to state.

F. MECHANISM OF HYPERALGESIA AND BURNING PAIN

A final point of general interest regarding pain transmission deserves comment. This concerns the mechanism whereby perception of pain is augmented, under special circumstances, by the development of hyperalgesia. Livingston (1943) has ascribed this perversion of sensory transmission to a special function of the spinal cord: "... under normal conditions the central activity tends to favor the transmission of the discriminative sensibilities and to inhibit pain impulses. Under abnormal conditions, such as involve a distortion of normal relationship, the pain pathway is thrown wide open and the passage of impulses by this route is facilitated. An abnormal situation of this kind apparently results in certain instances of injury involving the posterior columns, lesions of the central gray matter, and when long-continued and dominating impulses of painful intensity assault the central nervous system."** Riddoch (1938) stated that "under normal circumstances the points are set, from the posterior horns upwards, in favour of all those impulses which arouse discriminative sensations ...;

*Lewis, T.: *Pain.* Macmillan, New York, 1942, p. 141.

**Livingston, W.K.: *Pain mechanisms: A physiological interpretation of causalgia and its related states.* Macmillan, New York, 1943, p. 60.

appendectomy. War-time experience has shown that certain post-traumatic neuralgias may clear up after even a temporary increase in peripheral circulation, such as follows a malarial chill, intravenous injection of typhoid vaccine, or blocking the regional vasoconstrictor fibres with procaine. It is our conclusion that periarterial sympathectomy is about as efficacious as any of the above procedures, but that this is not due to any anatomical interruption of sensory pathways.

A final point that deserves clarification in connection with visceral sensitivity is the common error of alluding to visceral pain fibres as belonging to the autonomic system. By definition from the classic writings of Gaskell (1916), Langley (1921), and Cannon (1932) the autonomic system is a purely motor aggregation of pre- and postganglionic neurones which regulates smooth muscle and glandular activity for the control of homeostasis. For those who wish to adhere to this definition, as we do, it is therefore incorrect to refer to "afferent sympathetic fibres." It has undoubtedly confused many readers to be told that certain nerves are "sympathetic" nerves, but that the sensory fibres within them are not "sympathetic." The justification for this seemingly arbitrary terminology lies in the assumption that both the myelinated and unmyelinated viscerosensory fibres running in the autonomic trunks pass through the ganglion cells therein without synapses to reach their cell stations in the posterior root ganglia.* Our evidence that they run toward the spinal cord in both grey and white rami would be another reason for defining them separately from autonomic fibres As we have already remarked (p. 85), there is no anatomical evidence as to the locus of the cells of origin for the unmyelinated afferent fibres in the sympathetic trunks. Destruction at this level, as shown by Langley, results in degeneration of many of the myelinated fibres in the white rami communicantes, but no one to date has followed degeneration of these fibres to their end organs in the viscera. This has been done by Sheehan (1932) with the Pacinian corpuscles in the mesentery following splanchnicectomy, but it should also be carried out with the terminal cardiac and other visceral afferents.

In our lectures at the Harvard Medical School we have always insisted that visceral innervation is mediated by mixed nerves with distinct sympathetic or parasympathetic motor and somatic afferent components. In Lewis's (1942) words, there is no physiological sanction for regarding the pain nerves of the sympathetic nervous system as distinct from those supplying deep-lying somatic structures—"physiologically and anatomically pain

---

*Although pericellular nonmyelinated fibres sometimes seen around certain spinal ganglion cells have been thought to arise from the sympathetic system, Ramón y Cajal (1928) and de Castro (1932) have assembled imposing evidence that these are pathological dispositions which arise from the soma or the axone of the neurones within the same ganglion

tomical structure to that of physiological function. They depend on the presence of special types of nerve fibres which have defied anatomical verification and whose existence is no longer considered essential for the explanation of the observed facts.

As these hypotheses led to intensive investigation on the sensory apparatus and still influence neurological thought, it is important to review them briefly and cite the evidence whereby they have been superseded. The observations on which these thought-provoking theories have been developed and the evidence against them have been presented in great detail in the recent critical review by Walshe (1942) and in an earlier and simpler version by Cobb (1919).

1. Theory of Protopathic and Epicritic Sensibility

In 1905 Head, Rivers, and Sherren published a paper on "The afferent nervous system from a new aspect." Goldscheider and von Frey had previously discovered the punctate innervation of pain, touch, heat, and cold, but this classic article represents the first attempt to explain abnormal forms of cutaneous sensation. Therein are described observations made over a two-year period on the recovery of sensation after division and suture of the superficial radial nerve in Head's forearm. From a study of sensibility in the intermediate zone and recovery in the autonomous area of total sensory loss, they were led to postulate the existence of a dual system of sensory innervation–protopathic and epicritic. Protopathic sensibility, found at first in the intermediate zone and in the whole area supplied by regenerating fibres, is evoked only by painful stimuli and extremes of heat and cold. Such they considered to be the normal state of affairs in the cornea, glans penis, and internal organs. In addition they assumed that this type of crude sensation with a maximal ungraded response and diffuse, poorly localized appreciation of pain is the normal condition in lower animals. The return of light touch, appreciation of intermediate grades of warmth and cold, and two-point discrimination in the more advanced period of regeneration was ascribed to recovery of epicritic sensibility. Head, Rivers, and Sherren postulated that this is a higher evolutional form of sensation and that it inhibits the more primitive variety. In normal skin the two systems were supposed to supplement each other, with the epicritic suppressing the disagreeable intensity of the protopathic, as well as adding its own finer modalities of sensation.

These observations were purely functional, and no direct attempt was made to ascertain the actual existence of two distinct systems of receptive end-organs and conducting axones in the nervous plexuses of the human skin. Further complexities, such as the existence of a separate deep sensory

and it is only when stimulation of pain receptors is massive enough to overcome the inhibitory processes, that pain impulses become preponent." Inhibition may also be weakened by continued anxiety and general ill health, and under these circumstances pain develops with abnormal ease.

Foerster (1927A) and more recently Zotterman (1939) believe that this exaggeration of painful impulses may be due to an exclusion of the highly differentiated and phylogenetically younger system of cutaneous sensory fibres which run in the posterior columns, and which they believe exert an inhibitory influence upon the very ancient system of pain fibres. We are not convinced that this theory is tenable. If it were, posterior column tractotomy, which has been performed on a number of occasions (see p. 407), should have resulted in some sort of disagreeable sensation.

Wortis, Stein, and Joliffe (1942) suggested that a function of the fast-conducting pain fibres is to decrease the sensory response to the secondary wave of slower impulses. Hence a more intense conscious sensation ensues when the former have ceased to function. Gordon and Whitteridge (1943), who were able to record changes in speed of pain perception by changes in the cortical alpha rhythm, could demonstrate no abnormal delay in patients with dysaesthesia accompanying lesions of the peripheral nerves. Data from experiments of Bigelow, Harrison, Goodell, and Wolff (1945) indicate that when the threshold for "pricking pain," subserved by the larger and more rapidly conducting fibres, is elevated, the threshold for "burning pain," subserved by unmyelinated slow-conducting fibres, may be so depressed that ordinary innocuous stimuli are perceived as painful. Under these conditions even contact with bedclothes may result in burning pain, whereas sensibility to prick is impaired.* This phenomenon may be seen with disease or partial injury in thalamus, spinal cord, or peripheral nerves. It is therefore a result of abnormal function at any level of the nervous system and not confined to disease of the spinal cord

Past attempts to explain the peculiar variations of sensation following injuries to nerves and during the course of their regeneration led Head, Rivers, and Sherren (1905) to classify sensation into a primitive "protopathic" form and a more highly developed "epicritic" variety. Experimental observations on sensory transmission from irritated areas of skin likewise led Lewis (1937) to postulate a special system of "nocifensor" nerves to account for the phenomena of cutaneous hypersensitivity and hyperalgesia. Both of these theories have subordinated the study of ana-

*Numerous writers have referred to the state of exaggerated cutaneous sensitivity as *hyperaesthesia*. This is an error, as careful sensory determinations with von Frey hairs and a sensitive algesiometer will usually demonstrate an elevated threshold to both touch and pinprick. When pain does break through it may be of a burning character and intensely disagreeable. *Dysaesthesia* is then the more accurate nomenclature.

has ascribed the disagreeable quality of pain experienced in a hypersensitive area of regenerating nerve to the loss of normal insulation of the myelin sheath. This lack makes all regenerating sensory axones resemble pain fibres so that the result is an over-reaction to any stimulus in an exaggerated, explosive way; but after further regeneration and the redeposition of myelin this disagreeable quality of sensation disappears. We must, however, point out that there is no experimental evidence that it is the fibres which are eventually destined to have more myelin whose impulses are actually responsible for the abnormal sensations. Trotter and Davies also claimed that failure of recovery of accurate two-point perception does not require the assumption of a lack of regeneration of epicritic fibres, as it can be explained better by failure of reinnervation of many of the former sensory spots in the skin on which accurate localization depends. Anatomical evidence presented by Weddell (1941A) ascribes the normal quality of cutaneous sensation and spatial perception to a complex network of overlapping nerve fibres and multiple sensory terminals. In the phase of regeneration in which this multiple innervation is incomplete "there will be no anatomical basis for spatial summation; therefore reactions to stimuli will tend to conform to an 'all or nothing' law, leading to the characteristic explosive type of sensation, and there can be no recognition of gradation and no possibility of accurate localization."

Trotter and Davies's observations have been corroborated by Boring (1916) and Lanier (1935). It may be said in conclusion that no other observer has been able to confirm the essential facts on which Head's hypothesis was based. The terms "protopathic" and "epicritic," together with the theory that hyperalgesia results from lack of epicritic inhibition of the disagreeable quality of protopathic pain, must be abandoned.

2. The "Nocifensor" Nerves of Lewis

No investigator has surpassed Sir Thomas Lewis in acuity of observation of painful phenomena and their mechanisms. In his monograph (1942) he describes his studies on the mechanism of cutaneous hyperalgesia. He found that it may be produced by stimulating the trunk of a cutaneous nerve or any small branch, and also by injury of the skin. After any of these stimuli hyperalgesia develops within the entire area of the cutaneous nerve, and he adduces evidence that this is brought about through a richly arborizing system of nerve axones connecting every part with almost every other part within the territory of a given cutaneous nerve. Lewis ascribed the hyperalgesic state to the release of pain-producing substances in the skin mediated by nervous activity. He found that the reaction was not dependent on an intact sympathetic innervation and, as no anterior root fibres reach the cutaneous plexus, he felt that the voluntary motor system

supply and the difficulties encountered when the two systems reach the higher levels of the central nervous system, need not concern us here. We shall discuss this exceedingly complex theory only from the aspect of appreciation of pain. It is indeed tempting to ascribe the over-response to painful stimuli in the area of a regenerating nerve and the burning pain of causalgia to the action of uninhibited protopathic fibres, released by injury to the epicritic component.

Unfortunately, as Walshe has pointed out, "the exigencies of hypothesis have borne too hardly upon the facts." Not only have Head *et al.* postulated a dual peripheral mechanism, but also two separate central ones of distinct phylogenic development, viz., the thalamus and cerebral cortex. Here again they assumed the older protopathic level to be inhibited by the newer. The concept that the thalamic syndrome is a release from a higher epicritic level of cortical inhibition has since been proved untenable by the direct evidence that no such condition develops after removal of the postcentral cortex or after hemispherectomy. In order to account for these two separate sensory mechanisms Head was forced to hypothecate the evolutional development of a more complex set of epicritic nerves and receptor organs, whereas Walshe calls attention to the fact that the spinal cord has changed but little in the course of evolution, the peripheral nerves even less. He cites the statement by Sherrington (1940, pp. 278-279) that the "naive observer . . would have expected evolution in its course to have supplied us with more various sense-organs for ampler perception of the world . . . Not new senses but better liaison between old senses is what the developing nervous system has in this respect stood for." Walshe recalls that even in most primitive animal forms (polyps) there is sensation of an epicritic type. Finally, recent micro-anatomical studies of extreme refinement by Woollard, Weddell, and Harpman (1940) and Weddell (1941A) have left us no reasonable grounds for belief in the existence of two separate components in the cutaneous innervation

Head, Rivers, and Sherren's interpretation of their observations on sensory recovery can also be evaluated by comparison with more recent ones by others who have repeated this important experiment It has been carried out with added refinements a number of times. Trotter and Davies (1909) followed regeneration in themselves after section and suture of seven different sensory nerves. In general they were able to find no evidence of sensory return in two stages. All modalities tend to reappear together. The idea that there are two separate fibre systems for crude and delicate sensibility is not borne out by their observations, because in the hypaesthetic stage, when perception of moderate touch and thermal stimuli is lacking, stimuli of the same order but greater intensity are felt.

In a later paper on "The insulation of the nervous system" Trotter (1926)

From the practical viewpoint of the surgeon, the phenomena ascribed by Lewis to the activity of the nocifensor nerves do not play any definite role in the operative treatment of intractable pain. It is tempting to assume that they might explain the production of pain in herpes zoster. However, if this were true, relief from persistent hyperalgesia in the forehead might well be expected to follow division of the supraorbital nerve—a result which unfortunately does not ensue. Burning pain in causalgia, which often follows partial injury of a peripheral nerve, likewise cannot be attributed to nocifensor action. Its distribution is rarely confined to a single nerve trunk and it is often relieved by interruption of the sympathetic fibres, structures which Lewis found to be in no wise connected with his hypothetical system.

On the basis of the more recent studies of Wolff and the Oxford neuroanatomists there is no longer any need to subscribe to theories of special "nocifensor" fibres in the conduction of pain. Lorente de Nó, in a discussion of Wolff, Hardy, and Goodell's (1950) studies of hyperalgesia, stated that one of their most important contributions was the development of accurate methods of measuring sensory threshold. "The great difference in the theoretic results obtained by Dr. Wolff and by Lewis is due precisely to the fact that Dr. Wolff has developed an exceedingly accurate method of measurement . . . The fact that hyperalgesia developed without any change in the peripheral threshold of stimulation seems to me of tremendous importance in the physiology of pain. It places hyperalgesia in the central nervous system. The problem becomes that of the summation of impulses that have arrived at the nervous system through different pathways . . . a system of internuncial neurons that takes care of the summation of the stimuli . . . The only possible explanation I see is that the continuous arrival of impulses progressively decreases the threshold of certain neurons; a change of this kind will not be effective in producing hyperalgesia unless impulses from the periphery are arriving at the internuncial pool."*

This completes a rather brief review of the very complex and as yet not fully understood peripheral and spinal mechanisms whereby pain is transmitted from superficial and deep structures to the higher centres in the brain. Increasing knowledge of neurophysiology, based on critical experiments and quantitative measurements in the human subject, has given us a reasonably satisfactory basis for selecting suitable surgical methods of interrupting most forms of intractable pain, whether they arise in structures supplied by somatic or visceral nerves.

In order to avoid repetition, the role of higher centres in the perception

*Discussion of paper by Wolff, H G., Hardy, J D., and Goodell, H · Experimental studies on the nature of hyperalgesia. *Arch Neurol. Psychiat*, 1950, 63:188-189, courtesy of the American Medical Association, Chicago.

could not be concerned. The phenomenon occurs as long as the posterior roots remain intact and is limited to the area supplied by a single cutaneous nerve. Because Lewis supposed that accurate localization of sensory stimuli would be impossible if single pain fibres arborize over the entire distribution of a cutaneous nerve, he was forced to the conclusion that this response must be mediated by a new and distinct system of fibres. In Lewis's own words: "The fact seems to be that the pain nerves appear merely to register, through sensations that we call hyperalgesia, a state of skin for which they themselves are not responsible . . . Because the nerves are associated with local defence against injury and because they seem to belong to the same general system which is responsible for local flare surrounding skin injuries, I have named them 'nocifensor' nerves . . ."*

Like Head, Lewis's observations have led him to postulate a new and special system of cutaneous nerves without any anatomical proof of their existence. Yet, in contrast to the theory of protopathic and epicritic sensibility, it is far more difficult to marshal factual evidence against the nocifensor system. Walshe (1942) agrees with the dictum of Woollard, Weddell, and Harpman (1940) that "nocifensor reactions are mediated by the [ordinary] nerve apparatus subserving pain" and adds that there is nothing in Lewis's observations that forces us to postulate the existence of such additional specialized fibres. Tower (1943) has called the nocifensor nerves "an anatomical monstrosity." We have already referred (Chap. II, p. 16) to her oscilloscopic study of the functional field of interlacing individual nerve fibres in the corneo-conjunctival region of the cat; her astute interpretation provides, we think, an ample basis for precise localization of a single stimulus, eliminating the other reason for which Lewis hypothecates his new system of nerve fibres.

In the final analysis the most important factor which led Lewis to reject the role of ordinary pain fibres in the mediation of hyperalgesia was his evidence that the maximal areas of hyperalgesic spread are huge—for example, on the human forearm measuring 9 to 12 cm. long by 3 to 4 cm. wide. The largest area covered by pain terminals histologically demonstrated to arise from a single fibre is much smaller. But Tower offers an equally acceptable hypothesis to account for these large hyperalgesic areas, namely that "the hyperalgesia-producing substance presumed to be liberated . . . may activate, and thus recruit additional neuron units." Her own work on interlocking fields of individual pain fibres in the cornea lends credibility to this suggestion and eliminates the need for hypothecating a whole new system of nerves.

---

*Lewis, T.: *Pain* Macmillan. New York, 1942, p. 25

CHAPTER IV

PSYCHIATRIC CONSIDERATIONS*

PAIN AND PSYCHE are closely connected and the influence of one may profoundly affect the other. Pain may be thought of as a protective mechanism only as long as it helps the individual avoid harmful agents that jeopardize his health and safety. As Leriche (1949) pointed out, the idea that pain is always a beneficent mechanism constitutes "an extraordinary error, which has no justification." Under conditions where it becomes nagging and persistent, pain impairs the sufferer's ability to work and to think clearly, prevents his sleep, abolishes appetite, lowers morale, and may even destroy his will to help himself survive.

A. PAIN THRESHOLD

Certain individuals are born without a sense of pain. Descriptions of such rare congenital anomalies have been published by Ford and Wilkins (1938), Kunkle and Chapman (1943), Boyd and Nie (1949), and McMurray (1950). In the case reported by McMurray, Dr. W. H. Feindel was able to prove the presence of fine unmyelinated "pain" terminals in the skin by biopsies stained with methylene blue. These individuals seem able to adapt themselves reasonably well to the lack of this useful, if unpleasant, warning signal. The patient reported by Kunkle and Chapman, who had never experienced pain, was studied on the neurological service at the Massachusetts General Hospital.

> This young man, a cook in a nearby Army camp, was reported to have had a normal birth and no significant illnesses. He had, however, had rare spells with loss of consciousness since the age of eight; convulsive movements had been seen on only one of these occasions. He had been insensitive to pain as long as he could remember. He recalled specifically that he had never felt any discomfort when his teeth were drilled or following bruises or lacerations, including a cut from an axe which penetrated his shin to the bone. Although he was well aware when his bladder was full, he had no sense of real discomfort from this. He never experienced hunger, pain, or itching.

*This chapter, with the exception of the introductory pages, has been written by Dr. Stanley Cobb, Bullard Professor of Neuropathology, Emeritus, at Harvard Medical School and former Chief of the Psychiatric Service at the Massachusetts General Hospital, and by Dr. Frances J. Bonner, Assistant in Psychiatry in both institutions. Acknowledgment is also due the U. S. Public Health Service, which has generously contributed funds for the investigation of the neurosurgical approach to pain.

of pain at the conscious level and its localization, discussed in Chapter II, will not be elaborated further at this point. We have purposely avoided a strict anatomical-physiological division of these two chapters. It is quite impossible to discuss neuroanatomy without the aid of neurophysiology. On the other hand the problems of pain threshold, localization, and reference in their present theoretical state have seemed to us deserving of a separate chapter.

In ending this chapter it is important to point out that there remain extensive gaps in our understanding. We still have no satisfactory method for the interruption of pain in cephalic herpes zoster, the atypical neuralgias of the face and head, and some of the distressing sequelae to amputation and paraplegia. This is a constant stimulus to the surgeon with anatomical and physiological curiosity. While we can take just pride in the numerous effective procedures which have been developed within our own time, particularly for the control of intractable pain from the viscera, we still have many problems which urgently require solution. The answers are most likely to come from careful experimentation, a difficult problem when the ony suitable subject is the human being. As Waterston (1933B) has said: "An initial difficulty in the investigation of pain is that, at some stage or another, experiment is necessary on a sentient individual, and the unpleasantness of the experiments has doubtless deterred many investigators It can be overcome when the value and importance are realised of the information which can be thus obtained and by this means only."*

We have followed Waterston's suggestion to the extent that nearly every operation for relief of pain performed on cooperative individuals who are fair surgical risks has become an investigative procedure. The patient is fully informed of the study which has been planned and, if apprehensive, is sedated with intravenous Demerol or Pentothal in addition to the standard regional infiltration of procaine-adrenaline solution. With the help of highly trained anaesthetists it is usually possible to supplement the basal sedatives with inhalation of light concentrations of nitrous oxide or Trilene (trichlorethylene), so that the patient remains unconscious until the structures to be tested and cut are fully exposed. Despite this degree of narcosis, he will usually awaken within a period of 10 minutes so that the surgeon, if not pressed for time, can have a fully conscious and usually cooperative subject for testing. As soon as this has been completed the patient can again be put to sleep and, on awakening, will rarely complain of and often not even remember any discomfort.

---

*Waterston, D. "On pain" *Lancet*, London, 1933, 224.943-946, p. 943.

as inflammation may lead to such a lowering of their sensory threshold that manipulation under local anaesthesia may be distinctly felt (see p. 69).

Many interesting observations have been made by Hardy and Oppel's (1936) method of determining the cutaneous threshold to thermal radiation. As summarized by Wolff (1948), there is very little variation in the threshold of pain perception from one individual to another, or in the same individual from day to day. This is surprising, as one would expect pain threshold to vary from person to person just as much as the threshold for other senses such as smell or taste. In view of the fact that some individuals complain in such an exaggerated fashion of apparently trivial discomforts, one is led to question whether this apparently exact method tells the whole story. Dr. William P. Chapman, who has carried out the thermal radiation tests of cutaneous sensitivity at the Massachusetts General Hospital, has often pointed out to us that there is a more definite reaction in emotionally unstable individuals once the pricking sensation of heat has penetrated the skin. Individual variations in response to a painful stimulus, once it has reached the sensorium, rather than variations in the actual sensory threshold, may therefore account for the striking differences in behaviour exhibited by human beings to the ordeal of pain. In line with this hypothesis other investigators, such as Libman (1926), who tested the threshold of reactivity rather than the first perception of pain by exerting digital pressure over the styloid process, and Hollander (1939), who placed a rough metal grater under a sphygmomanometer cuff, found that American Indians, Negroes, and prize fighters did not react to noxious stimuli of an intensity sufficient to produce definite discomfort in the white urban dweller.

Accounts of what primitive peoples can undergo and what the more highly civilized were forced to endure in the past is brought out in a striking manner in Leriche's book on the surgery of pain (1949). He quotes Baron Larrey, who in his memoirs of the Napoleonic Wars mentioned an officer on whom he had done a shoulder joint amputation. This young man remounted his horse and was able to cross Europe, making the routine daily marches customary for the cavalry. What statesman of to-day could carry on as Richelieu did despite repeated painful abscesses from his anal fistulae? Our ancestors, however, did not always exhibit greater fortitude. The profound impression made on Samuel Pepys by being "cut for the stone" can be seen by reading his diary, in which he relates how he celebrated each anniversary of his operation by consuming Gargantuan quantities of food and drink. Yet even as late as the First World War Leriche records the apparent indifference to pain which he observed in certain Russian peasants. At the insistence of some aristocratic Russian "infirmières," who claimed that it was "unnecessary to put peasants to sleep, I amputated without any anaesthetic, but with a certain degree of reluctance.

> On neurological testing his general examination was normal. All other sensory modalities were normal, except for a moderate reduction in discrimination of heat and cold. On being pricked with a pin he was able to distinguish the point from a blunt object, but not through any sensation of pain. Probing of the nasal passages and muscle ischaemia evoked no pain, while testicular compression produced only a sensation of nausea. When he was tested by the Hardy-Wolff caloric method to determine the cutaneous sensory threshold, he noticed only a sensation of warmth when sufficient heat was applied to blister the skin. No headache was induced by intravenous injection of histamine. Yet he had an intact ciliospinal reflex, and touching the cornea, though painless, gave rise to a reflex closure of the lids. The ice-water test of Hines and Brown produced a pronounced rise in blood pressure.

From these facts Kunkle and Chapman inferred that this patient's sensory defect must be located at a sufficiently high level to spare segmental responses in the spinal cord and brain stem, while blocking "more complex and wide-spread body responses to pain which require the functional integrity of pathways to and in the suprasegmental nervous system." These observations should place the sensory defect at the thalamic or cerebral level.

Boyd and Nie (1949) in their report raised the question whether this form of analgesia represents a congenital anomaly at the highest sensory level in the postcentral cortex, or whether it may not consist of an aphasia-like incapacity to formulate a concept of pain. In his discussion of this paper DeJong doubted the existence of any bilateral lesion in the spinal pain pathway, thalami, or cerebral cortex. He concluded that the condition represents a form of sensory agnosia. The explanation remains *sub judice* because there have been no opportunities for postmortem examination.

As Leriche (1949) has suggested, some individuals are most unlikely to develop a pain syndrome Others, however, appear extraordinarily prone to do so, especially those emotionally unstable persons with cold, cyanotic, moist extremities, who often develop post-traumatic neuralgias after apparently minor injuries.

It is generally recognized that irritation of the peripheral end-organs results in a pronounced lowering of sensory threshold. This is seen after first and second degree burns and other forms of inflammation. These factors reduce the threshold not only of cutaneous sensation, but also of sensation in deeper structures. The passage of a needle through skeletal muscle, which normally causes little discomfort, may then become distinctly painful. This is a common observation for the surgeon who attempts to do a secondary operation under local anaesthesia within a few days of a previous procedure or traumatic injury. The same is true with the viscera,

Retrograde pyelography was also normal, but distension of the left renal pelvis appeared to reproduce his pain.

While on the ward the patient had several attacks of pain in which he simulated renal colic so well that the urologist, Dr. Charles Hazzard, was finally convinced that he should be explored. This was done in May, 1945, through an incision of the type used in thoracolumbar sympathectomy with removal of the twelfth rib. The kidney, which appeared normal, was denervated by stripping the nerves along its pedicle and resecting the sympathetic chain from T10 to L2, together with the splanchnic nerves. Recovery was uneventful except for radicular pain referred to the groin, and there were no further attacks up to his discharge from the Navy.

Four months later he wrote that he had suffered recurrent but higher attacks and remarked, "It almost seems to me that if you had gone up a little higher you would have completely severed all nerve communication." He even discussed the possibility of a further operation at a higher level. Fortunately he did not pursue this thought, because in 1948 he admitted to his wife that he had never had any actual pain. The attacks, which he was able to simulate so perfectly from reading medical textbooks, were always used to avoid undesirable military assignments. Thanks to Dr. Tiffany Lawyer, Jr., of the Montefiore Hospital in New York, we now have an illuminating psychiatric follow-up:

From this it appears that in 1938, because of reluctance to take his school examinations, he first complained of acute abdominal pain. Somewhat to his surprise, his complaints resulted in an appendectomy's being performed. A few months later he shot himself in the chest following an argument with his girl. He denied any desire to end his life and could give no motive for this act. Thereafter he was married and all went smoothly until his enlistment in 1942. He soon decided that shore duty at his second station was to his liking and that he wished to remain there. To this end he simulated the attacks of renal colic whenever he was included in an outgoing draft, admitted himself to the sick bay and remained there until the draft had departed. He then would write his own health record entry and stamp it with the medical officer's signature. In 1944 he was finally transferred to a P T. boat base in Rhode Island. As this station was a "living hell," he had many attacks there, for which he was finally transferred to the Naval Hospital at Chelsea, where he was submitted to cystoscopy and operation.

Dr. Lawyer reports that after discharge from the Navy B. continued to complain of bouts of pain whenever difficult problems arose in his life. Finally, when upbraided by his wife following a drinking bout, he admitted that all his attacks had been "faked" in deliberate attempts to gain his own ends and avoid responsibility. He recited this story of deception with no qualms and seemed most impressed by his success in duping all the physicians who had attended him. No guilt or remorse was evident. He was classified as immature and suffering from "character disorder with malingering."

three fingers of one Cossack and the foot of another. Neither of these men showed the least sign of pain." From the fact that Rasmussen and Freedman (1946) observed so many cases of severe causalgia in Chinese soldiers of the peasant class in World War II, the theory that pain is less of a problem in individuals accustomed to primitive conditions does not appear to be a valid one

Leriche told one of us that his Russian noblewomen mentioned above gave their patients icons to pray to during the operation. There is no question that the sensory threshold can be raised to a great extent during certain religious and mystic practices. Is this a form of self-hypnosis? Granted the patient is a suitable subject, hypnosis can be used as an anaesthetic for major surgery, as one of us witnessed at Kulenkampf's clinic in Zwickau 25 years ago The operation performed by Dr. Kulenkampf was a herniorrhaphy. The hypnotized patient evinced no evidence of discomfort, was able to cough on request, and when finally awakened was quite unaware that the operation had been completed. In Wolff's measurements on threshold of pain he found very definite elevations during states of suggestion, distraction, and excitement. This is why soldiers wounded in battle suffer so little (Beecher, 1946) and why injuries incurred during athletic contests or other extremes of exertion or emotion, when the sympathicoadrenal mechanism is working at maximal efficiency, cause so little pain Such, however, is far from the case with the patient dying of cancer or the sufferer from an acute toothache in the small hours of the night In these circumstances there is no solace from distraction and the pain is increased by introspection.

B. MALINGERING

It is important to bear in mind that the psychoneurotic individual or the malingerer may deliberately simulate illness and complain of intolerable pain in order to persuade the surgeon to operate. To detect this may require considerable psychological acumen, as illustrated by the following case:

John B., 24, a pharmacist's mate, was admitted to the U. S. Naval Hospital at Chelsea in 1945. He complained of intermittent attacks typical of left renal colic. These, he asserted, began in 1938, and he described the passage of a small calculus in 1944. The attacks were of such severity that they had often required 30 mg. of morphine for relief. Examination revealed a healthy-appearing young man with no palpable mass or tenderness in his abdomen. Urinalysis was normal. X-rays showed a small calcified shadow in the region of the right ureter in its intramural portion with slight blunting of the renal calyces. On the left, the painful side, however, nothing abnormal was seen.

that are disregarded because they are leading active and satisfying lives. But let any person find himself in a psychological jam, with anxiety, doubts, and depression; then the pain may bulk larger and larger and occupy more and more attention and energy. This is the sort of situation that apparently leads to many cases of neurosis in which pain is the presenting symptom. The different psychological pictures and reactions are, of course, almost as numerous as the patients.

In connection with the psychoneurotic background of a perplexing painful condition, Engel (1951) has made a remarkable report based on 20 individuals, 19 women and one man, who suffered from the syndrome called "atypical facial neuralgia" by Frazier and Russell (1924). Briefly this can be defined as pain in the face that does not follow the anatomical distribution of the trigeminal nerve, does not have the paroxysmal characteristics of *tic douloureux*, and is not relieved by interruption of the trigeminal nerve. Careful examinations by dentists, otolaryngologists, and radiologists are of course necessary to rule out local infection and malignant disease about the head and neck. The pains are usually of hours' duration and are described as deep, throbbing aches, sometimes sharp and shooting, or burning. The location varies from behind the ear, neck, and shoulder to eye, cheek, jaw, and teeth. There are often trigger points, which are tender to palpation and set off attacks. Local vasomotor signs are common, such as redness, swelling, and oedema. For years physicians interested in these phenomena have tried to implicate the sympathetic nervous system. No doubt many cases exist where local infection and other lesions cause secondary neuralgia of this sort. Engel, however, believes that, after weeding these out, there still remains a large group where the etiology is psychogenic and where the pain is an hysterical conversion symptom. His first case is described at some length and certainly supplies good evidence for his point of view. A dramatic injury in childhood, associated with high emotional tension, fixed the idea of facial injury and pain which was later elaborated by various neurotic mechanisms. The other 19 cases are much more briefly reported. A conspicuous character of these histories is that, although the patient may at first have insisted that her only trouble was facial pain, a careful investigation almost always revealed a host of neurotic reactions and symptoms woven into a complex and disturbed social history. Some of the patients were relieved by psychotherapy, but little is said about treatment. Engel tried electroshock treatments on a few cases and found that two or three treatments often gave relief for a few months, when the shock would have to be repeated. This suggestion might well be tried conservatively in conjunction with psychotherapy

The line between psychoneurosis and malingering is often difficult to draw. It depends largely on how deliberately the deception is practiced. A malingerer knows perfectly well that he is faking; a psychoneurotic patient is more or less unaware of his motivation—it is unconsciously motivated to a much greater extent than is the case of the malingerer. But even the malingerer who is perfectly conscious of his faking may not understand what drives him to behave in this way, so to some extent his motivation is unconscious, and he is to be looked upon as sufferng from psychopathological reactions. For example, in the case cited above the self-inflicted gunshot wound of the chest was an act much less understood by the patient than the later frank malingering episodes. Both, however, may represent related components of a basic "character disorder," i.e., his psychological development.

In the psychoneurotic patient the motivation and the mechanism of the symptom may be so deeply repressed that he has no idea that he is unconsciously faking a paralysis or exaggerating a small pain to gain certain psychological gratifications. The phrase "more or less unaware" was used above to emphasize that the acts we term "malingering" and those we term "neurotic" or "hysterical" have intergradations that are impossible to classify. Many patients with conversion symptoms have a dim awareness of what is going on and are quite on the defensive with the doctor. Others may have so completely suppressed all consciousness of the mechanism that they show "la belle indifférence" and are most cooperative with the doctor. There is no sharp line to be drawn between malingerer and neurotic.

C. THE NEUROTIC COMPONENT

One often hears a physician say of his patient that "he imagines his pain." In our experience with psychoneurotic patients we are inclined to think that this is rarely if ever true. Some pain, however slight, is almost always at the basis of the painful reaction. It may be neurotically exploited by exaggeration and introspection, so that the incapacity it causes is out of all proportion to the original pain. But in most cases the pain was there and its combination with anxiety made possible the neurotic reaction which led to consulting a physician. One of the commonest and most naïve examples is that of the adolescent girl, scared by the onset of menstruation, and ignorant and confused as to its significance, who comes to the emergency ward complaining of pain so dramatically that her normal appendix is removed. Unless helped psychologically at this time she may go on with this reaction pattern that leads to the "operation habit."

A pain as arresting as a menstrual cramp is not needed to become the focus of a neurosis. Most normal persons experience in the course of a day various aches and pains in muscles, joints, viscera, ears, eyes, or head

that are disregarded because they are leading active and satisfying lives. But let any person find himself in a psychological jam, with anxiety, doubts, and depression; then the pain may bulk larger and larger and occupy more and more attention and energy. This is the sort of situation that apparently leads to many cases of neurosis in which pain is the presenting symptom. The different psychological pictures and reactions are, of course, almost as numerous as the patients.

In connection with the psychoneurotic background of a perplexing painful condition, Engel (1951) has made a remarkable report based on 20 individuals, 19 women and one man, who suffered from the syndrome called "atypical facial neuralgia" by Frazier and Russell (1924). Briefly this can be defined as pain in the face that does not follow the anatomical distribution of the trigeminal nerve, does not have the paroxysmal characteristics of *tic douloureux*, and is not relieved by interruption of the trigeminal nerve. Careful examinations by dentists, otolaryngologists, and radiologists are of course necessary to rule out local infection and malignant disease about the head and neck. The pains are usually of hours' duration and are described as deep, throbbing aches, sometimes sharp and shooting, or burning. The location varies from behind the ear, neck, and shoulder to eye, cheek, jaw, and teeth. There are often trigger points, which are tender to palpation and set off attacks. Local vasomotor signs are common, such as redness, swelling, and oedema. For years physicians interested in these phenomena have tried to implicate the sympathetic nervous system. No doubt many cases exist where local infection and other lesions cause secondary neuralgia of this sort. Engel, however, believes that, after weeding these out, there still remains a large group where the etiology is psychogenic and where the pain is an hysterical conversion symptom. His first case is described at some length and certainly supplies good evidence for his point of view. A dramatic injury in childhood, associated with high emotional tension, fixed the idea of facial injury and pain which was later elaborated by various neurotic mechanisms. The other 19 cases are much more briefly reported. A conspicuous character of these histories is that, although the patient may at first have insisted that her only trouble was facial pain, a careful investigation almost always revealed a host of neurotic reactions and symptoms woven into a complex and disturbed social history. Some of the patients were relieved by psychotherapy, but little is said about treatment. Engel tried electroshock treatments on a few cases and found that two or three treatments often gave relief for a few months, when the shock would have to be repeated. This suggestion might well be tried conservatively in conjunction with psychotherapy.

D. HISTORY TAKING

It is of great importance to determine in patients with pain just what brought the patient to the doctor originally, particularly to the surgeon or neurosurgeon. This was strikingly shown in the following case:

Estelle R. MGH U-751515, came to the neurosurgeon complaining of severe pain in the jaw. Several years before she had had her teeth removed, following which a small area in the gum remained unduly sensitive. A careful history revealed that following the death of her mother, to whom she had had a very dependent attachment, the patient had felt completely lost. She divorced her husband, since her marital relationship no longer had meaning to her, and spent most of her time in travelling in an attempt to fill the "emptiness" that she had felt following her mother's death. In order to avoid frequent visits to the dentist, which had been necessary throughout her life to keep her teeth in good condition, she had decided to have them all removed. She returned to her mother's dentist to have plates made. As noted, following the removal there had been a soreness present in the gums which had persisted for a year and a half. Because the patient thought that the husband of an older sister was going to die soon (he had had a coronary thrombosis) and because she felt that this sister would "need" her, she decided to live with them. She found, however, that the situation made her "extremely nervous," and when the doctor, who came to see the brother-in-law, commented several times on her nervousness the patient quickly said that she was sure it was due to a soreness in her gums. She proceeded to have many minor operations and injections to relieve this. Although no cause could be found, these procedures were followed by an increase both in the pain and in the area involved until she considered a brain operation necessary to relieve her.

The neurosurgeon should be on his guard against such a case and recommend a prolonged period of psychiatric treatment.

Pain and suffering are not synonymous (see Chapter IX). Pain is only a part of the suffering undergone by the patient. It may be a large part or it may be a small part. To evaluate this is the important task of the psychiatrist. A mild pain may cause much suffering because of what it means to the patient. Men who have been exceptionally robust and healthy, leading active lives, may be thrown into a state of fear by a sudden illness with pain. Less healthy men who have suffered many illnesses may learn to tolerate a good deal of chronic pain and pay little attention to it. Samuel Johnson is an example of one who suffered much but whose intellectual drive and gusto for life kept him so busy that only severe attacks of gout incapacitated him. The matter of attention to pain is of great importance. Persons living happy and active lives full of interest can tolerate pain that would lay low the lonely and psychologically impoverished. But a person

who has appeared active and happy for years may have neurotic fears and reaction patterns that are lighted up by a sudden painful illness. As an example we will cite the case of a vigorous and active man suddenly affected by a slight cerebrovascular accident that left him with a thalamic syndrome.

A 52-year-old professor of Romance languages, who had served two years in the Army in Europe as an intelligence officer, had a slight cerebral thrombosis. This followed an unusually strenuous period of physical work. It caused numbness of the right half of the body and temporary slight weakness of the arm and leg. The numbness persisted. Two years later he stated that he felt "like a harlequin" and complained of a dull pain in the right side, especially in the arm, when he was fatigued. Neurological examination at this time showed only very slight awkwardness of the right hand and a slight reduction of strength of grasp. The deep reflexes were somewhat greater in the right arm and leg. Careful sensory examination elicited no abnormalities. His blood pressure was 150/90, occasionally higher, and there was no obvious arteriosclerosis. His general condition was good and he was muscular though somewhat overweight. Urinalysis and blood examinations were normal. The pain was described as deep in the right side, burning and aching in character, mostly in the arm and leg, especially the arm, but difficult to localize sharply. It was present most of the time, but was less troublesome when he was feeling well and interested, much more severe when he was tired, tense, and depressed. The increased pain made him more tense. It was relieved somewhat by alcohol, bromide, and Benadryl Drugs of the hyoscine group and barbiturates were not effective at all.

He was seen three times for hour-long interviews. Many emotional situations were brought up and discussed. The desire for peace and scholarly work was continually being frustrated by administrative work at the college and many interruptions from visitors at home. A sabbatical year was arranged with a fellowship to support him while he wrote a book on a favorite subject. During this year he was seen about once a month. More personal problems were brought up for discussion—fears of aging, family tensions, and childish, petulant reactions. The pain continued but occurred less often and disturbed him less, although it seemed to be of about the same intensity when it did occur. The commonest precipitant was noise, especially the confused noise made by a crowd of people. More interviews brought out his sensitiveness about personal contacts. His work was going quietly and interestingly. Eighteen months after the first interview his pain was negligible, occurring rarely and then not causing any depression, which he now recognized as fear. The next year saw the publication of his book and return to full-time work, but with a greatly reduced administrative load. The pain now occurs occasionally and the side still feels numb. The neurological examination has not changed.

In summary, this can be looked upon as a case of moderately severe

thalamic pain which was greatly increased by emotional stresses. Therapy consisted of ten psychiatric interviews in two years, with environmental management. Along with this there was gradual but marked reduction in the number and severity of the attacks. They still occur four and a half years after the first interview, but affect his efficiency very little.

E. LOCATION OF PAIN

In the patients we have studied the pain has almost universally been described as "it," an objectified stimulus which causes varying degrees of stress. On the whole the patient relates this stimulus to the "I" by describing "it" as present in a certain part of the body. In one instance, a patient with psychopathic personality and bilateral phantom limbs (Wylie S., MGH U-440170, whose case history is reported in further detail on p. 32), it was of interest that the pain, while objectified, was never related to the "I" in any way, although it extended into the stumps. He spoke constantly of the pain's being "there," as if describing an object present in the room but unrelated in any way. This is probably the most externalized sort of pain. It is in fact projected into a limb which is not there; it is actually an hallucination. Yet this sort of pain in a phantom limb is often associated with local irritation in the stump In other words, peripheral stimuli are necessary to start painful reactions. We know little of the complex processes that are necessary to perpetuate the pain, once it has started abnormal reactions at higher levels. A speculative theory as to what the mechanism of such "central pain" might be will be given in Chapter IX. Whatever the mechanism, the pain is probably accounted for by a complex of activated neurones set off by sensory stimuli from the periphery and modified and conditioned by central mechanisms. Such phenomena cannot be narrowly localized at any one level, peripheral, spinal, diencephalic, or cortical. But the main part of the disorder may be at one level more than another. The simplest example is peripheral pain due to pus under pressure stimulating nerve endings. Local operation relieves this promptly. Likewise pain in an amputation stump may be relieved by removal of a neuroma. In cases of "central pain," however, it seems as if peripheral stimulation, combined with central conditioning, had set up central activity which goes on long after peripheral stimulation stops or is set off by very slight peripheral stimulation. From those successful experiences of surgeons with cordotomy, gyrectomy, and leucotomy, the possibility that these abnormally functioning circuits may be spinal or cerebral must be considered. It would seem reasonable to suppose that those individuals in whom the neurological mechanism is most closely related to the highest levels of integration (corticothalamic and archicortical-hypothalamic—Cobb, 1950) would be most

amenable to psychotherapy. That is to say, the life-experiences of the person, preserved somehow as "engrams" in the cortical mechanisms, are responsible for important conditionings of the pain mechanism. The case discussed above of the man with a thalamic syndrome is an example. Psychotherapy relieved his highest level tensions, so that he was able to live with the residual thalamic pain.

F. PAIN IN PHANTOM LIMBS

Another and more complex situation is found in phantom limbs. As mentioned above, the pain is a projected hallucination, reflexly stimulated to varying degrees by peripheral irritation. The central mechanism is at the symbolic level; it has been classed with the aphasias by Efron (1951) and considered as the opposite of an autotopognosia (Cobb, 1947). The latter syndrome results from lesions in the region of the supramarginal and angular gyri in the parieto-occipital cortex (areas 7, 37, 39, 40) of the nondominant hemisphere or in the underlying subcortical areas. The psychophysiological result is a state in which the patient ignores his left limbs; to him they are nonexistent and painful stimuli applied to them do not reach his conscious awareness. The painful phantom limb can well be described as the exact opposite of this state, and it has even been suggested by Dr. Efron that an operation in this area to produce an autotopognosia should cure a painful phantom limb. If these speculations are worthy of credence, pain of this sort is integrated at a level as high as the function of knowing things, the receiving aspect of speech or gnosia, the lack of which is called agnosia or sensory aphasia.

White and Sweet, however, feel that it would be inadvisable to attempt to produce autotopognosia in any individual with a lower arm amputation, as it would so seriously cripple motor control of any useful stump or prosthesis (*cf.* Gooddy, 1949). Such a procedure would, if successful, be of great value in a painful shoulder or high arm amputation, where satisfactory lasting analgesia is so difficult to attain by cordotomy. On the other hand, they have seen patients with extensive resection of the nondominant parieto-occipito-temporal cortex for brain tumour, in which the entire hemisphere behind the first postcentral convolution had been resected, without any lasting loss of awareness of the contralateral extremities (unpublished observations). Penfield, whose experience with cortical ablation for epilepsy is vast, has written us that he has never seen a patient who had a parietal lesion lose sensation of pain excepting for a few hours or days following excision. Even when he has observed a very marked loss of awareness of the arm and its projection in space, this has usually cleared up after a number of months. Penfield therefore suggests that those patients who lose the sensation or awareness of pain must have subcortical lesions. J. L. Pool

(personal communication) has recently undercut a wide area of parietal and postcentral cortex of the nondominant hemisphere, including the primary sensory area in the postcentral strip, in a woman suffering from a phantom left upper extremity. Needles were first placed to mark the depths of Rolandic sulcus, and the major portion of the sensory cortex was then undercut by means of a leucotome inserted far back in the parietal lobe. According to Pool, this has "worked beautifully," relieving the phantom arm and hand pain for over a year without any noteworthy complication.

A complex case of phantom pain is given as an example to show that psychotherapy as an adjunct to appropriate surgery may help in returning a patient to a useful life:

A college teacher of 56 had a compound fracture of the right femur requiring immediate amputation at midthigh. Phantom limb phenomena appeared immediately and at first were annoying but not especially troublesome. Two years later he began to have a feeling of constriction in the stump of the right leg with paraesthesia and pain. In the phantom limb there was a burning feeling. Three years after the accident a neuroma was removed from the right femoral nerve in the stump. This gave no relief, so a month later a sympathectomy was performed in order to relieve the "causalgia." It was difficult to evaluate the results of the operation because herpes zoster developed in the left thigh. This was a flare-up of a former repetitive herpes in this area. When a few months of observation showed that no improvement had occurred, an operation for revision of the stump was done. This also gave no relief. The patient returned home on drugs and soon became habituated to barbiturates, several ounces of alcohol per day, and one or two hypodermics of morphine at night.

A year later the pain was still bad and the drug situation was incapacitating. He was admitted to another hospital for cordotomy, which was performed at T4 and failed to produce complete analgesia. After operation there was some relief of pain, but it was very difficult to assess how much relief there had been. The withdrawal of drugs caused much discomfort and the uncertainty about the success of the operation caused an anxiety state of marked degree.

He was seen by a psychiatrist at the hospital, who noted: "The operation has done much good, but the drugs and pain habit are now the problem." He was discharged to his home, where he was given much aspirin and Phenacetin and (at first) alcohol and morphine at night. He was seen once a week for an hour for discussions, which at first centered around symptoms and medicine, but gradually shifted to his basic psychological problems. There were marked tensions in his interpersonal relations. He had developed a strong feeling of inferiority at an early age and had reacted to this with a compensatory drive that had carried him to an educational and professional success far above that of his group. His marriage was most satisfactory, but the children had gone through many difficulties. All of these

and other sources of stress were discussed in a friendly way over the months of therapy. Gradually the burning pain in the phantom limb subsided, and the phantom itself became less obtrusive as his life became more normal and his waking hours occupied with interesting work. Eventually the nights improved and narcotics and analgesics were reduced. At last accounts, six years after the cordotomy, he was taking aspirin two or three times a day, 0.1 gm. of nembutal at night, and no alcohol except an occasional social drink. Morphine was only resorted to once in three or four months when a disturbed night would set up a vicious circle of anxiety, insomnia, and pain. The patient was successfully carrying a full-time laboratory and teaching program, for which he has wide professional recognition.

Kolb, Frank, and Watson (1952) describe three other cases where brief psychotherapy apparently relieved acute pain in a phantom limb shortly after amputation. Experience with a large number of cases has led them to believe that the painful complaint is often maintained by psychic mechanisms; that in certain cases it can be induced by reference to some known cause of anxiety; and that some comprehension of the individual's past experiences, in particular those that relate to the development of his attitudes toward his body, is necessary for therapy. They conclude that in certain cases of acute postoperative painful phantom phenomenon a brief rational psychotherapy may be effectively applied to relieve the painful symptom and associated panic. In addition, our experience suggests that proper preparation of a patient who is to undergo amputation might prevent in some instances the development of the painful hallucination. Such preparation could well be carried out by the surgical team and would include a discussion of the occurrence of the phantom phenomenon and a considerate inquiry as to the patient's wishes and fear in regard to the disposal of the part to be amputated.

G. ATTENTION AND DISTRACTION

The above case history brings up the problems of "neurosis," "central pain," and confusion after an ineffective cordotomy in a patient who has become habituated to drugs. The confusion of issues is the first problem to meet. The patients often have withdrawal symptoms as the narcotics are taken away. Even if there is no physiological withdrawal syndrome, the psychological hazard of giving up the support of drugs is often a great difficulty. The passive attitude of "I want you to give me relief" must be turned into an active attitude of "I will occupy myself and take interest in other people so that my pain is not the center of my attention." It is remarkable how great the effect of diverting attention may be on pain of any kind. Hypnosis is, of course, the most conspicuous example of the relief of pain by psychological methods. Major operations have been painlessly

performed under hypnosis. Women have gone through labour under hypnosis without pain. Hypnosis is a special phenomenon where suggestion reaches its highest efficacy in determining behaviour. Attention is a different phenomenon (Cobb, 1952). Physiologically it may be described as a motor-set, a state of alertness and readiness. Psychologically the important thing is the selectivity of attention. Were we unable to "focus our attention" and thus were equally attentive to all stimuli, we would be useless as efficient organisms. Our behaviour would resemble that of the manic patient whose distractibility lets his "mind jump from one thing to another" as fast as stimuli impinge upon him. Normal people have a mechanism that constricts the field of consciousness, so that the object at the centre of interest is intensely perceived while all others may be only vaguely sensed. That this process takes place at high cerebral levels may be shown by experiment. People attending an interesting demonstration have reported that they were completely unaware of things going on around them, yet under hypnosis they could be made to report accurately the various subsidiary things that had happened. The sense organs received the stimuli and the tracts carried them to the brain, but a mechanism at the highest level sorted out which stimuli should receive the spotlight of attention and which should be left in the shadow of subconsciousness. Thus a great mass of impressions are received and registered by our brains, and only a few are consciously remembered. Those that have the most attention are remembered longest.

Applying this concept to pain, one realizes that for most discomforts and moderate pains extraverted attention backed by an enthusiastic interest is the best analgesic. The common example of this is the patient plagued by neuritic, arthritic, or muscular aches when he awakens at 2:00 a.m., but who goes through the waking hours unconscious of his discomforts if he is sufficiently extraverted. The aim of therapy in many patients who have suffered for a long time, and whose attention has of necessity become centered on pain, is to divert their minds along constructive lines. Psychotherapy can show them that the passive desire to be cared for and relieved is a repetition of childhood reactions. Physiotherapy and occupational therapy can help bring the patient into a more normal contact with other patients and lead to a more extraverted attitude and way of life. While drugs are being taken away active measures must be instituted to get the patient up and out, to start new interests, and leave behind the invalidism. This is a rehabilitation that needs the skillful and understanding cooperation of surgeon, psychiatrist, and physiotherapist, as well as of family and friends.

II. THE PATIENT'S DESCRIPTION OF THE PAIN

The exact words used by patients to describe their pain are often diagnostically important. Terms such as "sharp," "stabbing," "burning," "throbbing" are common. Some patients are more dramatic and speak of a pain that "burns them up" or "as if a knife was jabbed into me and turned around" or "a gnawing pain as if I was being eaten away." Some of the descriptions are so vivid as to give the examiner the impression that the patient is suffering from an experience akin to a hypochondriacal delusion. It is a fairly good working rule that the more dramatic and detailed the description of the pain, the greater the psychogenic elements in the case.

Of interest in the descriptions of pain by patients is the fact that, although the pain in some instances is described concisely, in other instances the patient talks for some time in a circumstantial manner but vague as to the pain, rarely mentioning it and never describing it. Meredith G. (MGH U-540201), a 46-year-old female, when asked about her pain, talked for 45 minutes without interruption, going into great detail about each doctor she had seen, quoting what each had said to her and what she had said to them. Only twice, in passing, did she mention the pain. Such a patient would seem to have difficulty in her personal relationships, and neurotic reactions would probably be found on further examination.

The patients' descriptions of the onset of the pain vary. In some instances it is described as being associated with some medical event, some physical lesion or illness, such as a stiff neck. Noteworthy has been the fact that in a number of the patients, particularly in those in whom there is felt to be a large emotional element, the description of the onset is frequently vague and confused.

Many of the patients that we have seen have had multiple operations in an attempt to bring about alleviation. In their descriptions of the operations for pain, as well as of previous ones done for other reasons, we have two outstanding findings that seem to point to there being a large neurotic element in the illness: (1) the presence of "complications" following operation, these usually being in the nature of neurotic episodes or symptoms; and (2) pain becoming worse following operation. In some instances in (2) there has been a change in the character of the pain as well as an intensification.

I. THE PATIENT'S REACTION TO DOCTORS AND THERAPY

Although it is impossible to categorize all of these attitudes, some have seemed to us to suggest particularly a need for psychotherapy. The first is the patient with "polysurgical addiction" who, with little apparent affect, seeks out and goes through one operation after another, with possible tem-

porary relief of pain in one location and its later reappearance either in the same or a different location. The second is the patient who, although overtly friendly and claiming that the doctors are "wonderful," follows this with the statement that they have done nothing for her and proceeds in an attempt to manage the doctors, her medication, and all those with whom she comes in contact. This was particularly true in the case of Eleanor P., MGH U-295271, with a long history of psychoneurosis, who, following her husband's death, interpreted the fact that her extensive treatment, medical and surgical, had been at a relatively low cost because "the doctors owed it" to her. When she on occasion would be frustrated in her attempts to run the doctors, her medication, and those around her, she would then attribute what she considered her bad treatment to the fact that she was not paying the full fee.

The treatment of the professor with the phantom limb is a good example of the complexity of the problems. A good relationship to the doctor is one of the most important factors in therapy. One of our patients, reported in detail by Miles, Cobb, and Shands (1952), suffered from a myotatic dystonia with painful spasms. Her long illness and exposure throughout childhood to many doctors had terrified her. At first she was uncooperative, hostile, and drugged, until treated patiently for two months on the psychiatric ward. She had angrily refused operation. With psychological improvement the necessary surgical procedure became practicable and was successfully carried out. The result of combined surgical and psychiatric treatment has been much better than either would have been alone.

The patient's reaction to medication is of importance and the problem of addiction one that is frequently met in patients with intractable pain. Certain of the patients, their families, and hospital personnel as well have shown marked concern over the patient's receiving "needles" (narcotics) for the relief of pain. Other patients will note that the various medications given or tried have brought about no relief or alleviation of the pain, in spite of which they wish to be given something, and if medication is offered they will continue to take it although it does not help. A third group are the patients who are relieved by moderate amounts of medication, and in a fourth group are patients for whom medication does not bring about noticeable relief and who consequently prefer to take none.

Patients who fall in the last category are rare and are easy to treat for they are objective and reasonable. By far the commonest reaction of patients with chronic pain is a passive dependency on doctor and drugs which quickly leads to habituation. Withdrawal after operation is a difficult problem. It is best carried out in a hospital where there is strict control of visitors and nurses. It is practically impossible at home. Usually it is well to wait until the patient is entirely recovered from the operation and shows

a desire to get off the drugs and return to normal life. It may be necessary for a psychiatrist to take over in order to foster this constructive attitude or to accomplish the withdrawal after the attitude has appeared. Careful understanding of the patient's family, work, and social organization is essential to success.

In closing this chapter on the role of the psychiatrist in the evaluation and treatment of patients who present difficult problems of severe persistent pain, we wish to re-emphasize the following points:

Pain and its relief constitute one of the great problems of medicine. Both in the production of pain and its treatment psychological factors are of great importance.

"Real pain" cannot be distinguished from "imaginary pain" because the only true pain to the patient is what he feels. No other person can judge the intensity accurately. Individual reaction to pain varies enormously. Hypnosis, suggestion, placebo, and distraction can relieve both "real pain" and "imaginary pain." It is our experience that patients complaining of pain almost always have a physiological basis for the complaint, although neurotic mechanisms may greatly exaggerate the suffering.

There is no single objective way by which to measure the severity of the pain which a patient is suffering. In an attempt to evaluate the emotional response we have found the following criteria helpful. Although they are based largely on clinical observation and clinical impression, they may help the neurosurgeon to avoid those cases that will react badly to operation.

1. The patient's past performance in terms of social adjustment to school, work, marriage, family. Has he shown neurotic patterns?

2. The patient's reaction to stress situations in life, including his reaction to pain.

3. Observation of the patient in an interview as well as in the hospital situation. Is he passive, dependent, immature, demanding, hostile?

4. The patient's description of the pain: Is it concise and apparently objective, or is it excessively dramatic, vivid, and primitive? Are the locus and characteristics of the pain consistent, or does the patient on slight suggestion and direct questioning vary his story of reactions to many and varied types of pain?

5. The patient's response to medication: Does he quickly become dependent upon analgesics? Is he inquisitive and demanding in regard to drugs? Or does he seem to be reasonably objective?

The neurosurgeon must always be on his guard and endeavour to avoid operating on the severely neurotic patient until psychotherapy has been given a prolonged trial, although it may be of little help in many of these cases. In addition the psychiatrist may be helpful in handling the addicted patient after operation and during the withdrawal of drugs.

PART II

SURGICAL TECHNIQUE

INTRODUCTION

It is tempting to assume that present day anatomical knowledge and technical procedures at the disposal of the surgeon should permit interruption of pain from any structure or region with certainty. Such is unfortunately not the case, as is shown by the frequent reported failures to relieve the pain which follows herpes zoster, unusual neuralgias of the face other than simple tic douloureux, and many of those suffering from the phantom limb syndrome. The natural tendency of the surgeon after such a disappointment is to ascribe his failure to the psychoneurotic make-up of his patient. We prefer to put the shoe on the other foot and agree with Leriche (1949) that "if relief of pain does not follow operation it is usually not the patient who is to blame."

In the first place, it is important to recognize that, when afflicted with pain which is severe and of sufficient duration, even the most stable individual's morale can be broken down. This is particularly prone to occur when addiction to opiates or alcohol complicates the case or when the afflicted individual has been told by a series of consultants that he is neurotic or, in less diplomatic terms, a coward. Individuals who exaggerate their symptoms to gain sympathy and malingerers, who manufacture them out of whole cloth, certainly exist, but if there is an underlying etiological focus such as an amputation, visceral disease, or even a minor nerve injury it is always advisable to give the patient the benefit of the doubt.

The picture of intense suffering with apparent psychoneurotic overlay may develop after trivial-appearing partial injuries of nerves. The patient tortured by the burning pain of causalgia is not able to bear even the gentlest local contacts. In addition, he shuns the presence of others and all the minor emotional stimuli that cannot be avoided even in bed on a hospital ward. Time and again in the recent war wounded soldiers were told by inexperienced "neuropsychiatrists" that they were "yellow," a statement usually controverted by competent examiners and proven wrong by the immediate disappearance of their fretful appearance and neurotic behaviour following sympathetic denervation (see Chap. XI).

While dramatic recovery follows effective surgery, any ill-advised operation is bound to lower the patient's resistance and merely make matters worse. For this reason competent psychiatric advice is of vital importance, especially in cases of unusual pain which fit no recognized pattern. Although it is not too difficult to weed out the psychically inferior types, the malingerers, and the individual with a "compensation" neurosis, even the

most expert psychiatrists may find it impossible to say whether individuals with postoperative adhesions or other forms of obscure visceral disorder are suffering pain severe enough to justify a radical operation. Diagnostic blocking of the afferent pathways over which such pain should be transmitted has helped us solve some of these perplexing problems (White, 1947). The surgeon must be aware of the fact that any form of active intervention may result in transitory benefit through suggestion and he should therefore repeat the test on several occasions, observing not only the effect of a complete infiltration with procaine but also that produced by injecting inert salt solution, or that following mere placement of the needle in the proper position after an earlier injection has given relief. In spite of every precaution we must admit a few failures after surgery to achieve the result predicted by preliminary chemical block.

The following chapters of Part II concern surgical technique. In order to keep the size of this volume within reasonable bounds, the description of the various technical procedures has been made as short as clarity permits. Only the technique found most satisfactory by the authors is given, but in each case the reader will find references to more complete descriptions and alternative methods.

CHAPTER V

DIAGNOSTIC AND THERAPEUTIC NERVE BLOCK

THE OUTSTANDING TEXT on this subject is Labat's *Regional Anesthesia* (1924), on which most of our procedures are based. The last edition of 1924 is now unfortunately out of print and the author's untimely death prevented the completion of a projected rewriting. If this outstanding book is not available, we recommend that the reader refer to Lundy's *Clinical Anaesthesia*, published in 1942, which presents the subject in a brief, clear-cut fashion, or to the more recent and voluminous volume of Pitkin edited by Southworth and Hingson (1946). The descriptions which follow are limited to the essential steps necessary for the surgeon with some knowledge of local anaesthesia to obtain an accurate infiltration of the specific nerves and ganglia which are concerned with the most common types of neuralgia and pain from visceral disease.

In the selection of drugs for diagnostic blocking we have limited ourselves entirely to procaine, with small quantities of adrenaline added whenever it is used outside the spinal canal. The use of procaine for the purpose of simulating a contemplated neurectomy or sympathectomy is, with proper precautions, so safe and such a valuable adjunct in planning an attack on obscure types of pain that it should be used with far greater frequency. During the past twenty years we have relied on this method for widespread experimental studies on human pain. This has been a major factor in the development of effective measures for the relief of hitherto intractable pain in angina pectoris, thoracic aneurysm, pancreatic, biliary, and other forms of visceral disease (White, 1947).

Alcohol has been our agent for long-lasting chemical block, and we have had little experience with the shorter-lasting local anaesthetics made up with an oil base or with solutions of ammonium chloride as recommended by Judovich and Bates (1944). Alcohol is far from the ideal drug, but it is relatively safe and reasonably consistent in its action Recently Haxton (1949) in Manchester has advocated the substitution of 6 per cent carbolic acid in water. He has used this extensively in paravertebral lumbar block and thereby obtained impressive and long-lasting vasodilatation of the lower extremities. Haxton reported no instances of upper thoracic block with phenol, and we have had no experience with the method. F. A. Duncan Alexander and associates (personal communication), who have used 6 per

cent phenol in "many hundred blocks" at various points along the sympathetic trunk and into many somatic nerves, find its action "much more consistent" in the former than in the latter type of nerve. In studies after injection of the two agents into muscle, they find that absolute alcohol gives less erratic results upon injection into somatic nerves, and they correlate this with a larger area of local necrosis and a slower healing than they saw with phenol. Their only personal case of an irritative chemical neuropathy followed the injection of 3 per cent and 6 per cent phenol paravertebrally from T2 to T7. They mention three other such cases occurring after lumbar sympathetic blocks with phenol in the experience of colleagues elsewhere.

It should be emphasized that direct surgical interruption is usually superior to injection with alcohol, and that the use of the latter should be limited to the control of pain in patients with such advanced disease that operation under general anaesthesia would constitute an unjustifiable risk. We have also found nerve block with alcohol invaluable in the treatment of persistent pain arising from certain conditions which have hitherto rarely been submitted to surgical intervention. These consist of 1) cases of thoracic aneurysm in whom exposure of the thoracic sympathetic ganglia might result in rupture of the contiguous weakened aorta and 2) moribund patients whose limited days may be freed of the added burden of unbearable pain (see below, p. 127).

The reason for recommending direct surgical exposure rather than chemical block for therapeutic purposes is that alcohol has a very limited diffusion in tissue and no special affinity for nerves. Therefore the tip of the injecting needle must lie within a few millimeters of a nerve in order that the drug may penetrate its sheath. This objection of course does not apply to the subarachnoid injection of the cauda equina, where the delicate roots are devoid of protecting epineurium and can be more effectively sclerosed. In the case of the sympathetic ganglia and their visceral rami, technically perfect injection with permanent relief can be achieved in a fairly large proportion of cases. The results, however, can never be as consistently successful as those following surgical resection, and they are often complicated by chemical irritation and neuralgia of the adjacent intercostal nerves.

Attempts to block larger peripheral nerves with dense epineurial connective tissue sheaths are useless, unless the alcohol is injected directly within the sheath. This usually requires exposure through a surgical incision. Even under these circumstances the nerve fibres will regenerate through the zone of chemical necrosis, as reported by Smithwick and White (1930) after their attempts to relieve pain in cases of threatened gangrene from occlusive vascular disease. Guttmann and Medawar (1942) have shown that the reason for such rapid and perfect regeneration is that alcohol is

not a powerful tissue toxin. For the prevention of neuroma formation they have therefore proposed the intraneural injection of formalin or bacterial solution of gentian violet. Even formalin has failed in our hands. Therapeutic chemical block therefore has only limited uses.

A. DIFFERENTIAL SPINAL BLOCK

Spinal anaesthesia is a means of testing whether certain puzzling varieties of pain are transmitted by the spinal cord or projected from higher levels (e.g., the phantom pain of amputees). This at best is a crude method, as it blocks all types of conduction in the spinal roots. On the basis of studies on the selective vulnerability of nerve fibres of different sizes to local anaesthetic agents by Gasser and Erlanger (1929) and by Heinbecker, Bishop, and O'Leary (1934), Sarnoff and Arrowood (1946) in this hospital tested the action of very dilute concentrations of procaine within the subarachnoid space. Preliminary experiments in cats demonstrated that the thoracolumbar sympathetic discharge initiated by stimulation of the carotid sinus could be blocked, as well as pain conduction in the femoral nerve, while efferent conduction to skeletal muscle remained intact This selective block depends on the fact that the unmyelinated and thinly myelinated fibres, which conduct sympathetic motor and somatic pain impulses, are interrupted by lower concentrations of procaine than the more heavily myelinated, rapidly conducting axones which supply skeletal muscle and the more highly differentiated sensory end organs.

Wide experience with the method has now convinced us that differential spinal block may at times simulate the effect of a sympathectomy plus bilateral division of the spinothalamic tracts without impairment of muscular tone, reflex activity, or loss of touch, proprioceptive, and vibratory sense. Furthermore, a differential block of this sort can be carried upward with perfect safety to include the upper extremities, as full respiratory activity is maintained. The observations of Sarnoff, Arrowood, and Chapman (1948) have shown that visceromotor block precedes complete viscerosensory denervation, as some of these afferent axones are partly myelinated and therefore not as easily penetrated as the finer sympathetic fibres.

As differential spinal block is so simple to perform and so easy to control, we believe it preferable to high epidural block, which has been recommended by Hingson and Edwards (1943). At present we employ caudal block through the sacral hiatus only when we wish to test the effect of anaesthesia of the sacral roots.

1. Technique

A flexible lumbar puncture needle is introduced into the lumbar subarachnoid space. This is connected with rubber tubing and a drip reservoir for continuous intraspinal administration after the method of Lemmon (1940). The patient is then rolled onto his back on a split mattress and 10 cc. of a 0.2 per cent solution of procaine instilled by gravity flow in about three minutes. Thereafter 0.6 cc. per minute is allowed to run in while the loss of pinpoint sensation is followed upward to the desired level. Fifteen to 20 cc. usually suffice to produce a level of analgesia with added loss of temperature sense to the umbilicus and 50 cc. to the axillae, although much depends on the rate of injection.

This method has been of particular value in testing the effects of sympathetic denervation. Unfortunately experience has shown that it cannot always be relied on to predict the effect of spinothalamic tractotomy in obscure pain, as we have observed a number of patients who have had an exaggeration of their amputation stump neuralgia under differential spinal only to have it disappear under complete spinal anaesthesia. Under these circumstances it is always possible to inject the necessary greater concentration of procaine, but even this has at times given confusing results in the peripheral neuralgias (cf. patient Mahlon D., p. 268). We are reluctantly forced to admit that spinal anaesthesia is not a certain diagnostic test for pain and that it cannot be counted on to prove or disprove the effectiveness of sensory denervation.

B. *REGIONAL SPINAL ROOT BLOCK WITH ALCOHOL*

Intrathecal injection of ethyl alcohol to block the sensory roots of the cauda equina was proposed by Dogliotti in 1931. A number of papers have appeared in the American journals reporting successful results. As usual with new methods in medicine, the high proportion of failures to secure lasting relief of pain has not been publicized. The chief objections to this method are that quantities of greater than 1 cc. of absolute alcohol may paralyze skeletal motor fibres in the anterior roots and jeopardize control of the anal and vesical sphincters. On the other hand, a relatively safe dose of 1 cc. often fails to produce adequate and lasting analgesia. The limitations of the method have been brought out very clearly by the pathological studies of Aird and Naffziger (1935), and by reports of two cases of motor paralysis of the sacral roots by Tureen and Gitt (1936). Ten months after an injection in the dorsal region at another hospital Groff and Lewy (1941) observed intense arachnoiditis, demyelinization, and glial scarring in the posterior columns, with additional patchy degeneration in the other spinal tracts. This unfortunate patient had not been relieved of his original

complaint (angina pectoris), and he had suffered hyperalgesia of the entire body below the site of injection, in addition to spastic paralysis. They therefore concluded that alcohol should never be injected intrathecally above the level of the cauda equina. Even lumbar injection may be followed by this complication, as a patient at this hospital under the care of Dr. W. J. Mixter developed such a painful adhesive arachnoiditis of the cauda equina that he later required anterolateral cordotomy.

1. Technique

For unilateral blocking of the lumbosacral plexus the patient is placed on the operating table in the anterolateral position with the painful side uppermost and the upper hip and knee flexed. The table is then broken in order to produce lateral flexion of the spine and to place the pain-conducting posterior roots in the most superficial position (Fig. 23). The

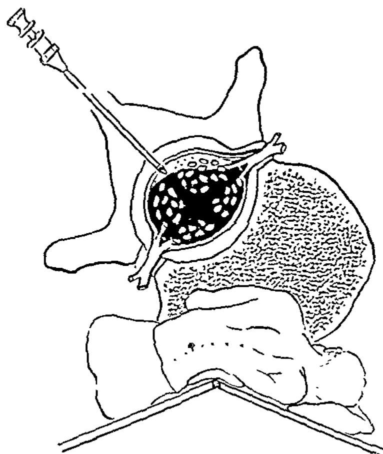


Fig. 23. Dogliotti's technique of intrathecal alcohol injection.
Method of positioning the patient so that the alcohol will be concentrated at the level of emergence of the sensory roots from the lumbosacral cord.

thoracic and sacral vertebrae must be dropped well below the level of the lumbar region. In positioning the patient every precaution must be taken to prevent the alcohol from pooling in the lower end of the thecal sac, lest it concentrate around the lowest sacral roots which innervate the bladder and rectum; also to prevent its diffusion upwards along the spinal cord.

Although it has been claimed that intrathecal injection with alcohol can be carried out with safety in the thoracic region, this has resulted in death from transverse myelitis (Groff and Lewy, 1941). Absolute alcohol (specific gravity of 0.775), being considerably lighter than spinal fluid (specific gravity of 1.005), will rise to the highest point in the subarachnoid space and selectively impregnate the desired sensory roots. It will penetrate finely myelinated and unmyelinated fibres, but tends to spare the larger and better insulated "A" and "B" fibres. As a result pain, temperature, and sympathetic axones are primarily interrupted.

Lumbar puncture is performed at the lumbar interspace where it is desired to centre the injection. When it is certain that the needle has penetrated the arachnoid, 1 cc. of absolute ethyl alcohol is instilled slowly and the needle then withdrawn. The injection causes no pain, only a sense of warmth followed by numbness over an area which includes a considerable

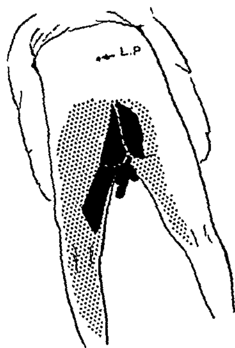


Fig 24. Area of anaesthesia following bilateral alcohol injection of lowest sacral nerves (Table I). Solid black indicates area of lasting analgesia. The larger area down the posterior thighs which is stippled indicates outlying zone of hypaesthesia immediately after injection This disappeared within a few hours Redrawn from White: *Surgery*, 1938. Courtesy, C. V. Mosby Co., St. Louis.

number of the lowest thoracic and upper lumbar, or the lumbar and upper sacral dermatomes. It is of utmost importance to keep the patient immobile for an hour in order to permit complete fixation of the alcohol before he is moved to his bed, where he should be kept flat until the following day.

Speaking from personal experience with some 20 of these injections, we have seen few complications but have had many disappointing results with only brief interruption of pain. When repeated injections have to be made for bilateral pain or because of previous failure, the risks of failure or complication are considerable. Larger quantities of alcohol should never

be used, unless under special circumstances it is justifiable to risk injury of the motor outflow to the legs, bladder, and sphincter ani.

A valuable modification of Dogliotti's method, which has a limited use, was published 15 years ago by one of us (White, 1938). This can be definitely counted on to produce anaesthesia over the distribution of the lower sacral nerves on both sides with little risk of weakening the legs. It must, of course, be used only in patients who are already on bladder drainage and who are willing to risk occasional soiling with faeces, unless they have a previous colostomy. There are, however, a small group of sufferers from inoperable carcinoma of the prostate, bladder, and lower rectum whose

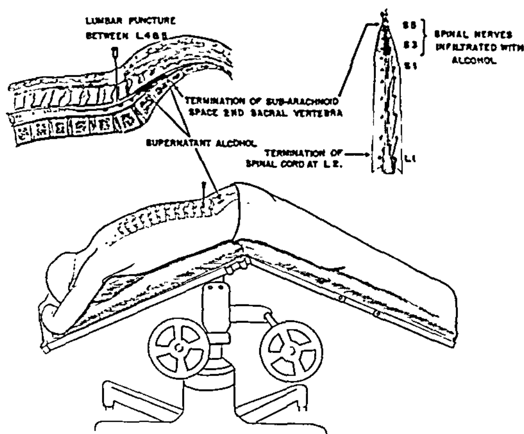


Fig. 25. White's modification of Dogliotti's method of intrathecal injection of alcohol.
Technique of bilateral subarachnoid block of lower sacral roots
From White: *Surgery*, 1938. Courtesy, C. V. Mosby Co., St. Louis.

pain is limited to the penis, perineum, and saddle area of the buttocks. By the time these individuals develop intolerable pain the need for an inlying catheter, suprapubic cystostomy, or colostomy has often been reached. Patients in the terminal stages of the disease with severe cachexia are extremely poor surgical risks for bilateral cordotomy, and even the loss of bladder or anal sphincter control may be a small price to pay for freedom

from pain during the final weeks of life. Distribution of the pain, however, must be limited to the lowest sacral roots, as shown in Figure 24. In cases where the disease has spread to the periosteum or lateral pelvic structures with involvement of the lumbosacral plexus and radiation down the legs, this simple method is no longer applicable.

Instead of making the injection in the lateral position, the patient is laid prone and the sacrum elevated by lowering the two ends of the operating table (Fig. 25). The caudal end of the subarachnoid space then becomes the highest point in the column of cerebrospinal fluid. Lumbar puncture is carried out at the lowest practicable interlaminar space. When the needle penetrates the arachnoid its position must be verified by aspirating spinal fluid with a syringe, because in this position pressure will be too low to permit its spontaneous outflow. Only a minimal amount should be withdrawn to check the position of the needle. One to 1.25 cc. of absolute alcohol is then injected. This floats upward to the caudal end of the thecal sac and impregnates the last three to four pairs of sacral nerve roots. The injection is painless and causes rapid loss of sensation over the saddle area of the buttocks, extending a short distance down each posterior thigh and forward over the perineum to include part of the scrotum or vulva with the penis or clitoris (Fig. 24). The patient, who has had sufficient medication to prevent restlessness or discomfort from the prone position, must not be moved for the space of an hour. He can then be transferred to his bed, but kept flat with the foot of the bed elevated until the following day.

2. Results

The protocols of seven patients treated by this method are summarized in Table I; on the whole the results have been most gratifying. The loss of cutaneous sensation has been confined to the distribution of the three lowest pairs of sacral nerves. While there has been immediate relief of pain in every instance, the duration of relief has been somewhat variable. In the case followed over the longest period (Patient 4), complete freedom from pain lasted for 15 months and at 20 months he still required no opiates. If the sensory fibres recover, reinjection is a simple matter. Two others had a gradual recurrence of their former pain. One of these was treated successfully by reinjection, but the second lives at such a distance that it was impossible for him to return to the hospital on account of his poor general condition.

Complications have been minimal. No patients have noted any weakness of their legs. As a rule the injection produces relaxation of the anal sphincter and an insensitive lower rectum, so that patients may soil themselves when their bowels are loose. None, however, has complained of frequent faecal incontinence. As far as bladder function is concerned, the

two patients with rectal cancer who were not already on constant drainage observed no impairment in their ability to urinate, although it seems too optimistic to believe that this will consistently be the case.

In spite of the fact that bladder paralysis may not ensue, subarachnoid alcohol injection undoubtedly carries a greater risk of this complication than bilateral cordotomy. It should therefore not be recommended for any patient who is not already on constant drainage or is not prepared to accept it. Inasmuch as the majority of patients with intractable pain in this area are suffering from cancer of the prostate or bladder neck, the necessity for an inlying catheter or suprapubic cystostomy has often been reached. Injection was performed in the two patients with rectal carcinoma because their poor general condition rendered cordotomy out of the question, but the intensity of their pain made them quite willing to accept the possibility of a catheter existence.

In conclusion, subarachnoid alcohol injection of the lower sacral nerves is not intended to supplant cordotomy in patients who are favourable operative risks, but for those who are in too poor condition and have only a short time to live it is a most valuable substitute.

C. PARAVERTEBRAL INJECTION

Blocking the viscerosensory axones by paravertebral injection of procaine was first proposed by Kappis (1923) and Läwen (1923), and its value further demonstrated by von Gaza (1924), Mandl (1925A), and Leriche (1949). Swetlow (1926B) proposed the use of absolute ethyl alcohol for permanent block of the cardiac nerves in angina pectoris. The effectiveness of this method for the treatment of pain in advanced coronary disease was reported in 1928 by White and White. Relief of suffering from painful aortic aneurysms (White, 1932) and a number of abdominal diseases where the patient's condition was too desperate to permit interruption of afferent pathways by sympathectomy, rhizotomy, or cordotomy has since been reported by White, Smithwick, and Simeone (1952). The diagnostic and therapeutic value of paravertebral block has recently been summarized and brought up to date by White (1947). While many surgeons and anaesthetists in the past have been reluctant to undertake these injections because they dreaded the technical difficulties inherent in such deep injections, it should be pointed out that this is no longer true. With the recent advantage of radiological visualization of the position of the needles in relation to well-defined bony landmarks, which we have developed, these procedures are no longer difficult and require only preliminary trial on the cadaver with a reasonable amount of patience and care.

TABLE I

SACRAL RHIZOTOMY BY INTRATHECAL INJECTION OF ALCOHOL

Patient	Diagnosis	Previous Operation	Symptoms	Alcohol Injection	Result
1. Male, 66	Carcinoma of rectum, recurrent in perineal scar.	Combined abdomino-perineal resection 1 yr previously	After good result for 9 mos., reopening of perineal wound with bloody discharge and deep perineal pain, liver enlarged and nodular	4/9/36. 1.2 cc 95% alcohol.	Complete relief for 2 wks., then recurrence. Unfortunately lived too far away to return for reinjection No disturbance in urination.
2 Male, 69	Carcinoma of rectum	Colostomy 2½ yrs previously.	Deep perineal pain and large, nodular liver with functioning colostomy.	4/17/36. 1.2 cc. 95% alcohol.	Local doctor wrote that, as far as he could judge, patient "did not suffer any great amount of pain" No disturbance in urination, but was able to retain rectal discharge less well. Died at 6 mos.
3. Male, 51	Carcinoma of bladder.	3/23/36. Resection and electrocoagulation. 10/23/36: Transurethral fulguration Suprapubic tube.	Severe recurrent pain from sacrum to penis with haematuria, dehydrated and in poor condition	11/16/36: 1 cc. 95% alcohol.	Severe sacral and penile pain entirely relieved. Died 11 days later of terminal pneumonia
4. Male, 69	Carcinoma of prostate.	9/22/36 Suprapubic cystostomy and permanent drainage	Bedridden and unable to rest on account of painful spasms in perineum and penis.	1/8/37: 1.1 cc. absolute alcohol	Complete relief of pain for 15 mos.; rectum remained insensitive so occasional soiling when bowels were loose. At 20 mos. slight recurrence of old pain but did not require opiates. Bladder full of cancer.
5 Male, 68	Carcinoma of bladder.	3/26/37: Bladder fulguration and implantation of radium seeds, suprapubic cystostomy Suprapubic tube	Bad pain on urination which radiated from sacrum through perineum to penis, much bladder irritability and frequency.	3/27/37: 1 cc. 95% alcohol. 6/4/37: 1.1 cc. 95% alcohol.	Complete relief for a month, then gradual recurrence, for which injection was repeated. Discharged relieved on following day. At 11 mos complained of some suprapubic discomfort, but old perineal pain seemed to remain relieved.

6. Male, 67	Carcinoma of prostate.	2/23/37: Vasectomy and permanent suprapubic cystostomy	Excruciating pain at base of penis on every movement.	4/10/37; 1.1 cc. absolute alcohol.	Complete relief of perineal pain with definite hypoaesthesia for 10 mos. At one year began to have slight recurrence, but morphine not required. At first some relaxation of anal sphincter but no leakage except with diarrhoea.
7. Male, 76	Carcinoma of rectum with extension to neck of bladder. On inlying catheter drainage of bladder, complicating coronary heart disease.	11/19/45: Exploratory laparotomy and colostomy. 1/6/47. Transurethral resection of bladder neck.	Intractable anal pain.	1/18/47: 1.2 cc. absolute alcohol.	Relief of pain at discharge with gluteal, perineal, and penile anaesthesia.

The first 6 cases have been previously reported by White (1938).

I. *Stellate Ganglion Injection by the Anterior Supraclavicular Route*

Following the original article by Leriche and Fontaine published in 1934, several methods of injecting the lower portion of the cervical sympathetic chain by infiltration against the transverse process of the sixth or seventh cervical vertebra *from the side have been described. One of the* best is that of Caldwell, Broderick, and Rose (1946), which is a modification of the descending-infiltration technique of de Sousa Pereira (1945). By making contact with the sixth rather than the seventh vertebra, risk of

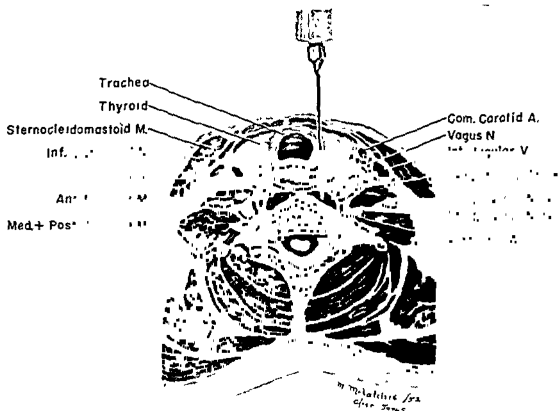


Fig. 26 Technique of stellate ganglion block by the anterior supraclavicular route.

pleural penetration and pneumothorax is greatly reduced, but procaine injected at this level cannot be counted on to infiltrate all the rami of the stellate ganglion to the brachial plexus and may therefore fail to produce an effective vasomotor paralysis of the upper extremity.

For injection of the lower portion of the cervical sympathetic trunk and stellate ganglion with procaine, we believe that the simplest and safest way is to proceed as follows. The patient is placed on the table in a semi-reclining position with the neck moderately extended over a small sandbag. The neck and upper thorax are swabbed with tincture of iodine and alcohol. A fine 5 cm. needle is then passed through the skin two fingers' breadth

above the sternoclavicular joint at the medial border of the sternomastoid muscle. If it is then worked inwards in a perpendicular parasagittal plane, it will pass just lateral to the trachea and oesophagus but well medial to the carotid sheath, vertebral artery, and apex of the pleura. At a depth of 3 to 5 cm. contact is made with the lateral portion of the body of the seventh cervical vertebra (Fig. 26). The tip of the needle will then lie in the thin belly of the longus colli muscle and close to the sympathetic chain in the prevertebral fascia. When the needle has made contact with bone, the syringe is attached and a test aspiration made, although penetration of any artery or the subarachnoid space is almost impossible. Injection of 5 to 10 cc. of a 1 per cent procaine-adrenaline mixture is made slowly without shifting the needle, which is then withdrawn. After over 50 trials in the past year our anaesthesia service has had almost no failures and only a single complication of transitory recurrent laryngeal palsy.

When an accurate infiltration has been carried out it will be followed by almost immediate congestion of the conjunctiva with the characteristic ptosis and miosis of a Horner's sign. Effective vasomotor and sudomotor paralysis of the arm has then invariably ensued, but injection by this method cannot be counted on to reach the lower cardiosensory fibres and it is not appropriate for permanent chemical block with alcohol. For these purposes the posterior approach should be used.

Stellate ganglion block may lead to a number of complications, no matter by what route the needle is inserted. Adriani, Parmley, and Ochsner (1952) have described a number of common and other unusual but serious sequelae. The danger of toxic reactions to the drug, pleural penetration with resultant pneumothorax, and intrathecal injection are described in the following section. When the needle is inserted by the direct anterior approach described above it is almost impossible to perforate the pleura, as at this level it lies somewhat lateral to the trachea and bodies of the sixth and seventh cervical vertebrae. Adriani *et al.* mentioned a case in which penetration of the oesophagus led to a low-grade local inflammation, which subsided on antibiotic treatment. This also is a most unlikely complication when the puncture is made between the trachea and the sternomastoid tendon because, contrary to anatomical texts, the oesophagus in the living subject lies entirely behind the trachea. This can be demonstrated by x-rays outlining the oesophagus with barium.

2. Injection of Thoracic Sympathetic Ganglia by the Posterior Route*

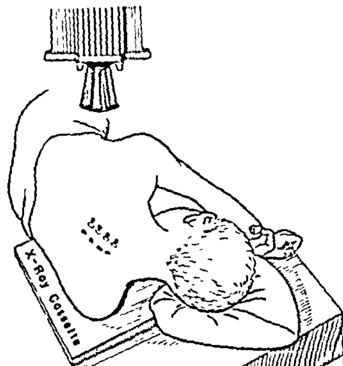
Although requiring somewhat more experience than the anterior route, this is the only way to infiltrate the ganglia below the stellate or the splanch-

*This section is largely reproduced from previous articles by White (1940) and White and Gentry (1944).

nic rami with either procaine or alcohol. Paravertebral injection of these ganglia is best performed with the patient lying on his side. He should be well sedated by preliminary morphine as well as by oral barbiturates, which Weiss (1929) has shown reduce the chances of toxic reactions to procaine. Particular care should be taken to ensure adequate sedation in patients with coronary disease, and it is also wise to order a 0.6 mg. dose of atropine sulphate subcutaneously as a protection against syncope and other vagal reflexes. If alcohol is to be injected for a permanent block or if the operator is inexperienced, it is a great help to place the needles against the anterolateral surfaces of the proper vertebrae under x-ray control, as first suggested by White and Gentry (1944). In these circumstances all that is necessary is to place the film holder under the patient and to have an x-ray tube mounted on a portable stand to expose the film after preliminary insertion of the needles (Fig. 27A).

The vertebrae can be identified by counting the spinous processes below the prominent seventh cervical. As these structures are imbricated downwards like shingles on a roof, the first thoracic lies beneath the spine of the seventh cervical and so on downwards over the entire extent of the thoracic spine. The patient is placed on his side, back and shoulders close to the edge of the table, legs drawn up, head flexed forward and supported on a thin pillow so that there is no lateral curvature of the cervical spine. In order to test the accuracy of upper thoracic block, it is also important to have both hands exposed so that they can be observed for changes in circulation and sweating. It is advisable in addition to make sure that the patient is not bearing too much weight on his lower arm and that he will be comfortable even if held in this position for over an hour.

The technique of inserting the needles is essentially Labat's (1924) second method of paravertebral injection. The bony landmarks are the spinous processes. Procaine is injected intradermally 4 cm. lateral to these points. Twenty-gauge lumbar puncture needles 8 to 10 cm. in length are inserted at these points and pushed inward perpendicularly to the skin until the transverse process or the articulating portion of the rib is touched at an average depth of from 2 to 5 cm. (Fig. 27B, first position of needle). It is important to visualize the depth of the ribs in order not to penetrate the pleura and puncture the surface of the lung. If this happens, a spontaneous pneumothorax occasionally develops in the course of a few hours. Once contact has been made with bone, the tip of the needle is manipulated caudad until it touches the lower border of the transverse process. The depth marker is then pulled out to a distance of 3 cm. from the skin. Each needle is now inclined to an angle of approximately 20 degrees with the median sagittal plane and perpendicular to the curvature of the back in relation to the long axis of the thorax. When thrust inward on this bearing



B.

Fig 27. Technique of upper thoracic ganglion block by posterior approach

White's modification of Labat's (1924) original method of paravertebral injection. A. Placement of patient on x-ray table for checking position of needles inserted for paravertebral infiltration of upper thoracic sympathetic ganglia. B Cross-section diagram to show method of inserting needles for paravertebral infiltration of upper thoracic sympathetic ganglia.

From White: *Surg. Clin. North America*, 1947. Courtesy, W. B. Saunders Co, Philadelphia.

a second contact is usually made with bone at a further depth of 3 cm. (Fig. 27B, second position of needle). If sooner, the needle must be withdrawn and re-inserted at a slightly lesser angle. On the other hand, if no contact is made at 3 cm. the needle must be directed further toward the midline.

The paravertebral ganglionated chains lie at an average depth of 3 cm. beneath the transverse processes, running along the anterolateral surface of the vertebral bodies and looping over the heads of the ribs. The farther forward the tips of the needles can be inserted and still maintain their contact with bone, the less alcohol will come in contact with the intercostal nerves and the greater amount will surround the cardiac or splanchnic rami. A useful trick in working the tip of the needle forward alongside the vertebra is to start with the bevelled tip pointed medially. When bone is touched, the tip of the needle can often be made to scrape along it if the needle is rotated through 180 degrees so that its bevelled tip is turned away from the bone. A depth of even 4 cm. beneath the transverse process is quite safe, provided the tip of the needle still rests against bone. An infiltration in this region will diffuse freely through the retropleural space, bathing the spinal nerves, the sympathetic trunk, and its cardiac or splanchnic rami.

During the placement of the needles the syringe should never be attached. Care should be taken that the tip of a needle does not lie within the pleural space, in a blood vessel, or in an outward prolongation of the subarachnoid space. None of these eventualities is dangerous, provided it is recognized and the position of the needle corrected. With the tip touching bone, it is almost impossible for it to lie within the pleura. Rapid inspiration of procaine placed in the butt of the needle or a cough reflex on injection indicates penetration of the pleural cavity. If the needle has entered a blood vessel or the subarachnoid space, aspiration of blood or spinal fluid will make these complications obvious. Bloody taps are frequent under the upper two ribs because the large intercostal branch of the costocervical artery parallels the first and second thoracic ganglia. Spinal fluid is more rarely aspirated, but the possibility of a high spinal injection of either procaine or alcohol is a serious matter. This is most likely to happen if the needle is passed over the upper border of a rib in a cephalad direction. We have withdrawn spinal fluid twice, and know of three instances of intrathecal injection of either procaine or alcohol. When all of the needles have been properly placed they should form a characteristic pattern with their shafts lying parallel, in the same sagittal plane, and inserted to the same depth.

For diagnostic block with procaine all that is necessary is to inject 5 to 10 cc. of 1 per cent procaine-adrenaline solution slowly into each needle, and a single needle will usually suffice to block a considerable length of

the sympathetic chain. If properly placed, this amount of anaesthetic solution produces clear-cut signs of intercostal and sympathetic paralysis within a period of *two to 10 minutes.* Sympathetic block is particularly striking when the upper thoracic ganglia have been injected in an individual whose hands are cold and sweaty from nervousness.

In cases where alcohol is to be injected it must be borne in mind that procaine diffuses through the retropleural tissues far more widely than alcohol. Alcohol must be infiltrated in close proximity to each ganglion that is



Fig. 28. Technique of paravertebral injection of thoracic sympathetic ganglia under radiographic control.

Lateral x-ray to show position of ganglionated sympathetic chain in upper thorax in a cadaver. The position of the inferior cervical ganglion is marked by the loop in the wire (retouched). That of the succeeding 5 thoracic ganglia is shown by the dural clips. Note that the cervicothoracic ganglion lies nearly at the anterior edge of the first thoracic vertebra.

From White and Gentry: *J. Neurosurg.*, 1944, by permission of the editor.

to be destroyed. Experience has shown that unless a clear-cut block can be produced with a minimal quantity of procaine, there is no assurance of a lasting paralysis with 5 cc. of alcohol.* We have found it best to check the position of the needles with lateral x-rays of the spine to ensure that their tips lie well forward in contact with the sides of the desired vertebrae.

The position of the ganglionated sympathetic chain is shown in Figure 28. This x-ray was made from a cadaver in which the position of the sym-

*Five cc. of alcohol injected into the thigh muscle of a rabbit causes an area of necrosis little over 1 cm. in diameter.

pathetic trunk was marked by a metal wire and the ganglia by dural clips. By comparing this view with Figure 29 made in the course of an actual paravertebral injection, a good idea is given of the depth to which the needles must be inserted to assure the maximum concentration of procaine and alcohol around the upper four thoracic ganglia and their cardiac rami. The first and second thoracic ganglia lie nearly at the anterior edge of the corresponding vertebral bodies.

Considerable care must be taken to ensure injection of the first thoracic ganglion. Due to the moderate kyphosis of the upper thoracic spine, the operator tends to insert the upper two needles in an increasingly caudal direction and, because 7 to 8 cm. of the needle lies hidden beneath the skin, it is hard to realize that the tip of the first may actually be placed caudad to the second. In this case no alcohol will reach the first thoracic ganglion, and the relief of angina pectoris will often be incomplete. We believe that this accounts for the frequent failure to obtain a definite Horner's sign, and that it is of great importance to make sure that the shafts of all four needles lie parallel to one another. Such a mistake will be brought out clearly and the error prevented if the position of the needles is checked radiographically prior to injection.

When alcohol is to be used it is best to inject only a preliminary 2 cc. of 2 per cent procaine and to follow this with an additional 3 cc. of 1 per cent, once it is established that the needles have been placed correctly. This supplementary injection is to ensure a widespread anaesthesia so that the final injection of alcohol will be painless. The additional dilution of the alcohol does not seem to prevent an effective destruction of nerve tissue.

The final injection of 95 per cent alcohol is carried out very slowly; a total of 5 cc. is injected through each needle, but the plunger is drawn back after each cubic centimeter has run in to make sure that the needle tip cannot have shifted and penetrated a blood vessel or the subarachnoid space. All together several minutes should be spent in injecting the alcohol through each needle. If the patient complains of any undue discomfort, the injection must be stopped for a few minutes until the pain subsides.

After the needles have been withdrawn it is best to keep the patient on his side with his back supported by a pillow and as quiet as possible for an hour or more, in order to minimize diffusion of the alcohol. He may then be shifted over onto his back and after two hours allowed to assume any desired position in bed. Most patients can be up on the following day and leave the hospital within 72 hours.

The following early complications have been observed in our patients:

Pleuritic pain has been troublesome in four patients within a few hours of the injection. This has appeared as the procaine has been absorbed, and it is surprising that it is not of more frequent occurrence. One or at most



Fig. 29. Technique of paravertebral injection of thoracic sympathetic ganglia under radiographic control.

Lateral x-ray to show position of needles taken during an actual paravertebral injection. This 78-year-old woman had such intense angina decubitus with attacks on any exertion or emotional stimulus that she was considered an impossible risk for operation. Following left paravertebral alcohol injection she was relieved of her cardiac pain for six months During this period she was able to rest and eat in comfort, so that her general condition was vastly improved. When she later suffered a recurrence of angina pectoris her upper thoracic posterior roots were cut without serious complications.

two injections of morphine and chest strapping have invariably given satisfactory relief.

Severe pleuritic pain developed during injection in one case. This was probably caused by alcohol leaking into the pleural cavity. It necessitated large doses of morphine but subsided within six hours.

Pneumothorax has appeared within a few hours after injection in two patients. The cause of this is penetration of the pleura and puncture of the lung so that air continues to leak from the injured alveoli for a number of hours. In one asthmatic patient aspiration was necessary for the relief of dyspnoea.

Although no instance of intrathecal injection has occurred in our personal series, we have withdrawn spinal fluid on one occasion and have always worried over the possibility of this most serious complication. The precautions which can be taken to avoid it are these: 1) Never slide the needle over the upper border of a rib in a cephalad direction; 2) always insert the needle detached from the syringe; and 3) draw back on the plunger at frequent intervals during the actual injection. In spite of these precautions one of our colleagues produced a high spinal anaesthesia in the course of a diagnostic procaine injection. However, if a volume of only 2 cc. of 2 per cent solution is used as a test for the position of each needle, the risk of injecting this small amount (40 mg.) is practically negligible. Failure to recognize the fact that procaine has entered the subarachnoid space is serious if a sufficient quantity of the drug is introduced so that respiratory paralysis is induced. Even in this event effective artificial respiration and other standard methods of resuscitation should carry the patient through the transitory period of respiratory failure. During the war, however, a fatal accident occurred because procaine was injected by one of our residents without proper precautions, and he then made the mistake of leaving the room for a few minutes. When he returned respirations had ceased and it was too late to resuscitate the patient. Two similar fatalities have recently been reported by Adriani, Parmley, and Ochsner (1952), while a third patient who developed respiratory paralysis recovered after prompt institution of artificial respiration. Whenever paravertebral injection is undertaken, at any level from the cervical to the sacral spine, it is vital that the possibility of respiratory paralysis be borne in mind and that the anaesthetists be prepared to institute immediate effective measures for its control. For this reason we always carry out these procedures in the operating room with the cooperation of the anaesthesia service. Under proper observation, if no abnormal anaesthesia or other danger sign develops and the needles are not shifted, the risk of infiltrating procaine or alcohol intrathecally must indeed be very slight. Molitch and Wilson (1931) have recorded a Brown-Séquard paralysis, which came on almost immediately

after a paravertebral injection of alcohol beneath the first rib. Fortunately the patient subsequently recovered from her paralysis and was relieved of her anginal pain. One other such accident has been reported to us. This also occurred following injection for angina pectoris, but no details are available.

Two other alarming sequelae that may follow the injection and rapid absorption of local anaesthetic drugs have been reported by Adriani *et al.* (1952). These are due to reactions to the drug either from intolerance or a toxic concentration in the blood. They fall into two groups, the stimulating or convulsive and the circulatory depressant type. The former is easily diagnosed and the convulsions controlled by intravenous injection of Pentothal. The other causes coma accompanied by a fall in blood pressure and a weak, thready pulse. The treatment consists of immediate intravenous injection of Neo-Synephrine and preparations to open the chest for cardiac massage if the heart should stop. We have never seen this complication, possibly because we have always ordered prophylactic atropine and a barbiturate before the patient is sent to the operating room.

There have been no late complications after procaine block, but after injection with alcohol some degree of intercostal neuralgia is a frequent occurrence. This is a really troublesome complaint in 10 per cent of these patients. The sympathetic ganglia lie so close to the intercostal nerves that alcohol infiltrated around the chain cannot help bathing their trunks. They are paralyzed at first but anaesthesia begins to disappear in their anterior divisions within a fortnight. Within a month the intercostal nerves are recovering along their entire length, and with this there is a greater or lesser degree of dysaesthesia of the chest wall. Most patients state that pressure of clothing irritates the tender skin and that there is a burning sensation with occasional shooting pains. In most cases the discomfort is quite bearable and clears up in a month or two. In others, about 10 per cent, it is more troublesome and requires mild sedation with acetyl salicylic acid or empirin compound, phenobarbital at night, and occasional doses of codeine. Baking the hypersensitive areas is often a great help. With the exception of a neurotic woman and one other individual in whom the injection failed to relieve the anginal attacks, the patients have all stated that they would willingly submit to a second injection if their attacks should ever recur.

There is no question but that neuritis constitutes a serious objection to treatment by alcohol injection. In advanced coronary disease its disadvantages are less than the increased risk of mortality from operation, but it precludes the application of the method to any but the severer cases of coronary insufficiency and the terminal stages of malignant disease.

3. Injection of Splanchnic Nerves

Although Labat (1924) has described a method for the direct paravertebral injection of the splanchnic trunks beneath the diaphragm where they enter the coeliac ganglia, we prefer to inject the lower thoracic ganglia with their splanchnic rami above the diaphragm. This will ensure a more complete interruption of afferent pathways from the liver, pancreas, kidney, and upper intestinal tract. White and Smithwick have been able to carry out lasting blocks with alcohol in this way for pain in desperate forms of visceral disease (see White, Smithwick, and Simeone, 1952, and Chap. XIX).

4. Injection of Lumbar Sympathetic Ganglia

Diagnostic injection of these structures is done more often for the evaluation of circulatory conditions than for states of intractable pain. Nevertheless we have found the method of value in cases of causalgic pain in the lower extremities and in an unusual instance of intense pain from embolism occluding the aortic bifurcation. It is also advisable to inject the first lumbar in addition to the lowest thoracic ganglia in diagnostic block for chronic renal pain, as accessory afferent pathways from the kidney may reach the sensorium by this route.

When paravertebral injection is to be carried out in the lumbar region, the same general directions and precautions apply that have been outlined above. The injection is most conveniently performed with the patient lying in the lateral position (Fig. 30). The points for inserting the needles should be marked 3 cm. lateral to the upper edge of the lumbar spines, and cutaneous wheals should be raised with 1 per cent procaine.

Next, 10-cm. needles equipped with depth markers are thrust through these wheals and pushed inward perpendicular to the plane of the back. They should make contact with the transverse processes of the corresponding vertebrae at a depth of from 3 to 6 cm., according to the muscular development or obesity of the individual. If immediate contact is not made with bone there is no risk of penetrating the peritoneum, because of the interposed belly of the psoas muscle.

Once the transverse processes have been located, the depth markers are set to measure an added depth of 3 cm. Each needle is then pointed slightly upward to pass above the edge of the transverse process and slightly toward the midline. Contact should be sought with the side of the vertebra at the added depth marked on the shaft. In carrying out this manoeuvre the tip of the needle scrapes along the side of the vertebra and is protected by the overlying belly of the psoas muscle (Fig. 30). The sympathetic rami follow this same route in connecting the lumbar nerves with the gangliionated chains. If each needle is slid well forward on the lateral surface of the

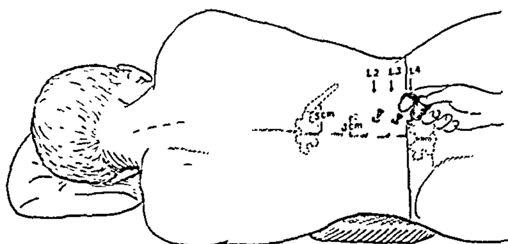


Fig. 30. Technique of paravertebral injection of lumbar sympathetic ganglionated chain From White: *Surg. Clin. North America*, 1947. Courtesy, W. B Saunders Co., Philadelphia.

vertebra, its tip will lie close to the anterior edge of the psoas muscle. Procaine or alcohol reaching this level can be counted on to infiltrate the retroperitoneal tissue at the edge of the aorta and vena cava and to bathe the sympathetic trunk. At the same time there is little, if any, infiltration of the lumbar plexus of spinal nerves, which lies in a more dorsal plane protected by the psoas muscle. As in the case of paravertebral injection of the thoracic ganglia, it is important to make certain that none of the needles has pene-

trated a blood vessel or the subarachnoid space. Aspiration will show this.

In carrying out a temporary block with procaine one should inject 5 to 10 cc. of a 1 per cent procaine-adrenaline solution through each needle. This should give rapid warming and drying of the lower leg and foot with a variable degree of anaesthesia over the lumbar dermatomes and at times loss of motor power in the iliopsoas, adductor, and quadriceps femoris groups of muscles. When alcohol is to be injected one should make a preliminary injection with a minimal amount of procaine (2 to 2.5 cc. of 2 per cent solution) to test the proximity of the needles to the sympathetic trunk, just as described above for alcohol injection in angina pectoris. If clear-cut signs of sympathetic paralysis fail to appear within ten minutes, the needle must be withdrawn and the procedure repeated at a later date. Such failures can be avoided by using radiographic control in inserting the needles (Fig. 31). Once it has been ascertained that the needles are correctly placed, it is best to increase the amount of procaine injected to a total of 5 cc. in order to ensure thorough anaesthesia before alcohol is introduced. Five cc. of 95 per cent alcohol is then injected slowly through each needle. Although annoying neuralgias are less frequent here than in the thoracic region, where the intercostal nerves are more exposed to chemical irritation, there is bound to be a certain proportion of failures due to the limited diffusibility of alcohol.

Haxton (1949) has recently reported more successful long-lasting chemical blocks following the use of 6 to 10 per cent phenol in this region, which he has used in over 200 cases. It is claimed that this more powerful agent destroys the ganglion cells and produces a lasting sympathetic interruption. Favourable results have been obtained in a variety of circulatory disorders and complications have been few. Lumbar ganglionectomy is such a simple and well tolerated procedure that we have only found a single case where it seemed necessary to substitute chemical block with alcohol. This patient suffered continued intolerable pain after a rider embolus which occluded the bifurcation of the aorta.

D. INJECTION OF GASSERIAN GANGLION AND ITS BRANCHES

Injections of the two lower divisions of the Gasserian ganglion as they emerge from the cranial cavity and of the peripheral branches in the face are procedures of great diagnostic and therapeutic value. Skill in their performance must be cultivated for treatment of trigeminal neuralgia in the very aged and infirm, and also for preliminary treatment of certain advanced cases where the severity of the neuralgia has exhausted the patient through lack of sleep and inability to chew or swallow his food. As a diagnostic aid injection is invaluable for weeding out the atypical neuralgias, which are only made worse by section of the Gasserian root. Before resorting



Fig 31. Technique of paravertebral injection of lumbar sympathetic ganglionated chain.
X-ray of needles in position and distribution of infiltrated opaque contrast medium.

to retrogasserian neurectomy, even in the typical tic douloureux, we consider it advisable always to perform a temporary block with alcohol, as this will give the patient an opportunity to evaluate the annoyance that some individuals experience with anaesthesia of the mouth and cheek Sometimes temporary relief from severe trigeminal neuralgia is necessary prior to operation, as these individuals may be dehydrated and semistarved because of intense pain on mastication and swallowing Transitory periods of sensory loss do not always predict the rare but serious late complication of anaesthesia dolorosa. The following case history is given to illustrate this hazard:

Isadore W., MGH U-4731, 68, a junk dealer developed typical tic douloureux in the first trigeminal division. His attacks disappeared after alcohol injection at the supraorbital notch, and when they recurred they were again completely relieved by a section of the descending trigeminal tract in the lower medulla. This operation was chosen because he worked in dusty surroundings and it carries far less risk of paralytic keratitis than a retrogasserian neurectomy. The relief again was not permanent and after nine months it was necessary to cut the upper fibres of the trigeminal root. This has resulted in satisfactory relief of his intermittent neuralgia, but has been complicated by intense burning pain in the anaesthetic area of the eye, forehead, nose, and upper cheek. The anaesthesia dolorosa became so intense and such a continuous torture to the patient that bilateral frontal leucotomy had to be undertaken as a final resort. He is now relieved of his suffering, but continues to be a serious problem in the home on account of mental deterioration (see p. 320).

As pointed out by Grant (1936), most descriptions of the technique employed for injecting the maxillary and mandibular divisions of the trigeminal nerve give the impression that this is a relatively easy procedure. Although this is true of diagnostic injection with procaine, a drug which can be used in sufficient quantity to infiltrate a relatively wide area of tissue, it is far from the case when it is desirable to obtain a long-lasting anaesthesia with the small quantity of alcohol which it is safe to inject. Effective interruption with this agent necessitates injection directly in contact with the sheaths of the nerves, structures which average only 3 mm. in diameter and lie at a depth of from 4.5 to 6.0 cm. beneath the skin of the cheek (Fig. 32).

Anaesthesia following an accurate infiltration usually lasts from three to 12 months. Unless the drug has entered the ganglion its effect is never permanent, as the sclerosing action of alcohol is slight (Guttmann and Medawar, 1942) and the scar is easily penetrated by regenerating axones.* Permanent interruption of sensation results only when alcohol penetrates directly into the Gasserian ganglion and its nerve cells are destroyed. This may take place in the course of injection of the mandibular nerve by the lateral route, or when the tip of the needle has been successfully inserted through the foramen ovale from below by the method described by Härtel (1933).

For injection of the mandibular and maxillary divisions we have used the method developed by Levy and Baudouin in 1906, which has been popularized in this country by Patrick (1907, 1912) and in England by Harris (1926). Excellent descriptions are available in a more recent article by Grant (1936). A technical improvement recently proposed by one of

*Only in the case of the tiny visceral rami to the heart and abdominal organs can long-lasting relief of pain be obtained by chemical blocking of nerves.

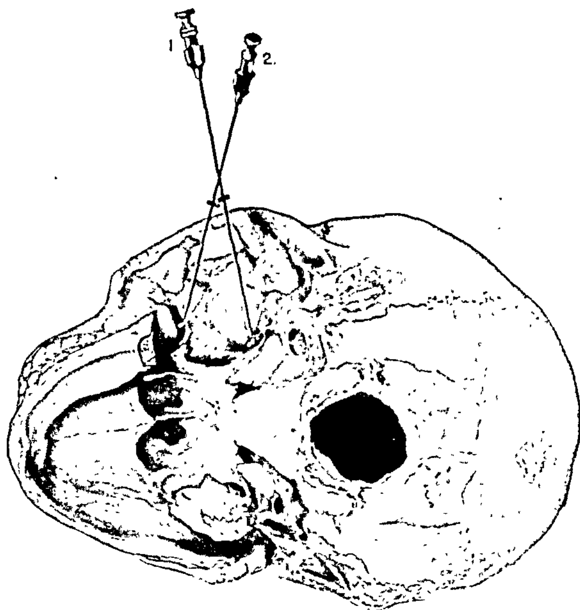


Fig 32. Under surface of skull to show position of needles for injection of (1) mandibular nerve at foramen ovale, (2) maxillary nerve in pterygomaxillary fossa.

our associates, Dr. Bertram Selverstone, is the use of an electrically insulated needle. A standard 20-gauge lumbar puncture needle, its shaft coated with insulating varnish* except for its tip, is inserted in the usual manner. One pole of a standard square wave 30 to 60 cycle stimulator is connected to this, the second to an inert electrode placed beneath the opposite cheek. After the needle has been inserted in the usual manner the effect of stimulation is tested. When the current reaches the nerve characteristic tingling paraesthesiae or, in the case of the mandibular nerve, forcible closure of the jaw are evoked. With this method in the hands of Dr. Selverstone and

*Excellent material for the purpose is sold by Belden Manufacturing Co., 4647 W. Van Buren Street, Chicago 44, Illinois, U.S A.

one of us (J.C.W.) experience has led to the conclusion that when 0.2 to 0.3 volt gives a definite response the needle tip must be in actual contact with the nerve, but when 0.5 volt or more is required contact has not been obtained and the position of the needle requires correction. This simple modification has resulted in a notable increase in the effectiveness and duration of our nerve blocks.

I. Mandibular Nerve Block at Foramen Ovale

When this injection is performed the patient should be lying on his back on the operating table with the head supported on a thin pillow and rotated exactly 90 degrees. As infiltration of alcohol causes intense pain, the patient should be well sedated but not to the point where reliable responses cannot be obtained. *Edentulous patients must wear their false teeth or have the* jaws separated by biting against a soft cork or roll of bandage. A line drawn from the tragus of the ear to the tip of the nose marks the lowest point in the sigmoid notch of the mandible (Fig. 33). The lower edge of the zygoma should lie about 15 mm. above and the space between these two lines marks the area of unobstructed access to the zygomatic fossa. A point marked 2 cm. in front of the posterior margin of the condyle of the mandible (the bone felt on palpating the anterior wall of the external auditory meatus) and beneath the forward slope of the mandibular tubercle of the zygoma should lie just opposite the foramen ovale (Fig. 32).

A procaine wheal is raised at this stage 1 cm. below the lower border of the zygoma and further infiltration with 2 to 3 cc. of the anaesthetic solution carried down to the level of the mandibular notch. A 20-gauge lumbar puncture needle is then inserted on a bearing of 90 degrees to the long axis of the skull and pointed slightly upwards at 110 degrees in the vertical plane. The needle should be fitted with a depth marker of fine rubber tubing to limit its maximum insertion to 5 cm.* Occasionally the needle will impinge against the bony edge of the sigmoid notch. It will then be necessary to lower the mandible by using a wider jaw prop. Should the needle not make contact with the base of the skull at 4 cm. it should be partly withdrawn and reinserted upwards at a greater angle. Once bone is encountered the needle tip can be worked along its smooth surface. No anatomical protrusion obstructs its advance (Fig. 34). If inserted at the correct angle with the vertical axis of the skull it should reach the foramen ovale at an average depth of 4.5 to 5 cm. Pain or paraesthesia is often produced in the lower lip, chin, and/or tongue as the nerve is encountered. However, in the recorded experience of one of us (Sweet, 1950) two-thirds of a group of 45

*In an individual with a very broad skull and thick cheeks the foramen ovale may lie deeper. Harris (1926) records an extreme example where the foramen lay at a depth of 6.7 cm.

patients gave no such helpful cue when the needle point was correctly placed as shown by x-ray and subsequent anaesthesia on injection of alcohol. This substantial majority had no pain at all, or referred the pain entirely outside the zone of supply of the mandibular division, or else com-

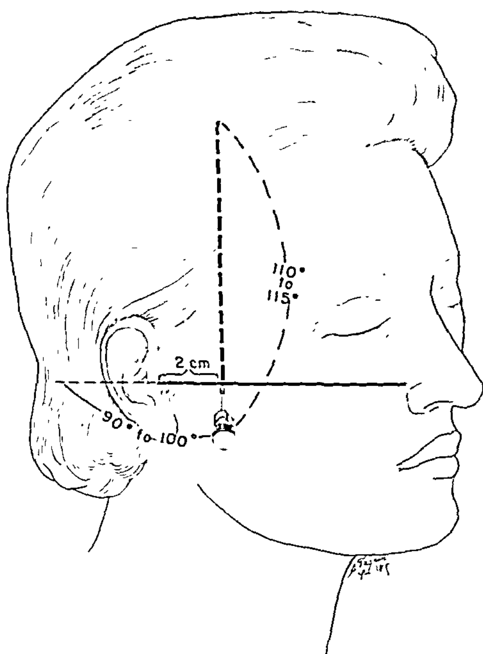


Fig. 33. Superficial landmarks and bearings of needle for injection of mandibular nerve at foramen ovale.

plained only of local pain at the site of the needle. Hence we prefer in most instances to carry out the injection with the assistance of radiographic control, a tactic which has yielded the desired analgesia in 95 per cent of the injections tried (Fig. 35). This result has been attained with less pain to the patient than when the same operator sought the correct position by re-

peated probings. If one is not using roentgenographic aid and is not reasonably certain of a proper placement of the needle (when, for example, the patient has suddenly complained of very severe local pain), it may be well to inject 0.5 cc. of 2 per cent procaine and watch for the appearance of hypaesthesia. If this sign is not obtained careful rechecking of bearings and exploration with the needle must be continued until its position is verified beyond a doubt. As the foramen ovale may lie slightly behind the bear-

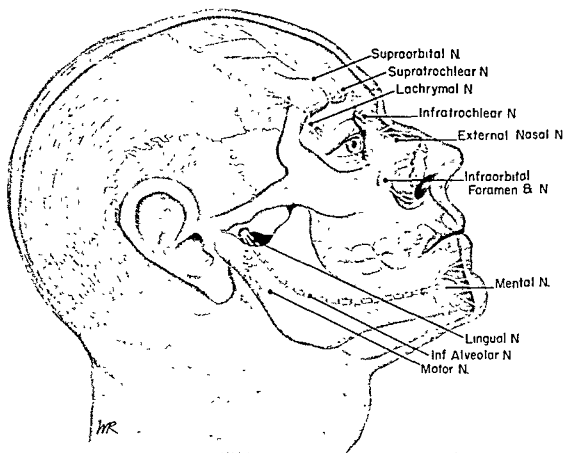


Fig. 34. Anatomical relationships of foramen ovale and mandibular nerve.

ing of 90 degrees, it is well to point the needle slightly more posteriorly if paraesthesias are not produced in the normal position. If it is pointed too far posteriorly the Eustachian tube may be pricked, causing pain deep in the ear; pain experienced superficially in the ear or just in front of it indicates contact with the auriculotemporal branch of the nerve. If the needle in inserted too deeply the nasopharynx is entered. Occasionally arterial blood may escape from the needle due to penetration of the internal maxillary artery. No serious haematomas are produced provided the needle is withdrawn and pressure applied to the cheek for a brief period.

However, skulls vary sufficiently from person to person so that these directions are only approximate. In Figure 36 we have charted in a small series the actual measurements of the position of a needle whose point was shown by x-ray to be in the foramen ovale and injection into which pro-



Fig. 35. Radiographic localization of needle in mandibular block. Insert shows position of skull and x-ray tube in position for submento-vertical projection of foramen ovale.

duced analgesia throughout the third division. One notes the frequent substantial variations from the mean figures we have cited. Indeed this sort of variability appears to have led Cushing (1920A) to say regarding trigeminal injection, "This is more or less of a gift, and there are no rules to follow. One introduces the needle to the nerve.”

Once the needle has made contact with the mandibular nerve, absolute alcohol is injected a drop at a time, to a total of 1 cc. This produces intense pain followed by numbness radiating over the territory of the mandibular

nerve Despite the temporary severe discomfort we believe that injecting alcohol without preliminary procaine is more likely to result in effective lasting block Furthermore the first few drops of procaine entering the trunk of the nerve may also cause severe pain. Spread to other divisions of the nerve indicates either too deep insertion of the needle directly into the ganglion, or central diffusion of the alcohol into the ganglion consequent upon placement of the needle-point within the nerve trunk at the foramen. By the time 1 cc of alcohol has been injected the skin of the chin, lower gums, and anterior two-thirds of the tongue should be totally anaesthetic.

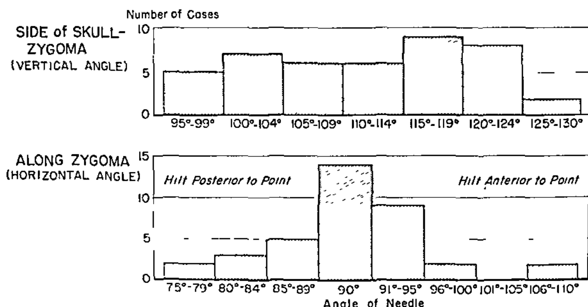


Fig. 36 Angulation of needle in position for successful alcohol injection of the mandibular nerve.

If the point of the needle lies in the space occupied by rootlets immediately behind the ganglion or the alcohol is by some channel diffusing freely into the cerebrospinal fluid-containing region of the root sheath, the injection may be painless (as in lumbar subarachnoid alcohol injection). The danger of facial paralysis accompanying trigeminal anaesthesia is then present. One experience in which such paralysis followed the uninterrupted injection of 1 cc. of alcohol in a patient whose needle point was shown by x-ray to lie in the centre of the foramen ovale has caused us to check the patient's sensation after each additional few tenths of a cubic centimeter of alcohol.

Within a few hours after injection the patient can be permitted to carry on his usual activities. Final determination of the extent of anaesthesia should be postponed to the following day and the procedure repeated, if necessary under x-ray control, should it prove ineffective. Complications are rare provided precautions are taken to avoid injection of alcohol into

the Eustachian tube and against too deep insertion of the needle through the foramen ovale. Harris (1926) in particular stresses the danger that may come from too deep penetration. Not only has permanent injury to all the lower cranial nerves resulted from alcohol reaching the subarachnoid space behind the ganglion and spilling over into the lateral recess, but deaths have been reported from injury to the more deeply situated internal carotid artery within the cavernous sinus. Such misfortunes can be avoided by careful control of the depth to which the needle is introduced and observation of the effect of the preliminary injection of procaine.

2. Maxillary Nerve Block in the Pterygomaxillary Fissure

The preparation and position of the patient for injection of the maxillary nerve is identical with that described above, only the point for insertion of the needle lies 1 cm. further forward and the nerve itself 1 cm. deeper. A medium-sized lumbar puncture needle, with rubber marker set at a maximum depth of 6 cm., is inserted through a procainized wheal 1 cm. below the zygoma and 3 cm. in front of the anterior bony edge of the auditory meatus. The structure one actually feels is the posterior surface of the condyle of the mandible. The jaws should be held apart by means of a dental prop in edentulous individuals. The needle is advanced at an angle of 115 degrees with both the vertical and long axes of the skull, i.e., it is pushed forwards as well as upwards. It thereby points on a level with the external canthus of the eye but more posteriorly, as though aimed at the optic nerve (Fig. 37). Bone of the pterygoid plate of the sphenoid should be met at a depth of about 5 cm.; if one encounters bone at a depth less than this, the tip of the needle is usually directed too far forward and is in contact with the maxilla. If it penetrates deeper it may be within the pterygomaxillary fissure in proper position or too far posterior and behind the pterygoid plate. When the needle tip touches the pterygoid plate it is usually a simple matter to work it forward to enter the pterygomaxillary fissure (Fig. 38). At an added depth of 0.5 to 0.75 cm. it should make contact with the nerve, resulting in sudden radiation of pain to the upper lip and side of the nose. If no pain or paraesthesia is produced as the needle enters the pterygomaxillary fissure, the needle must be partly withdrawn and reinserted in a slightly higher or lower plane.

When the needle tip has penetrated the nerve, injection of a drop or two of 95 per cent alcohol nearly always produces a sensation of "spray" and is followed by hypaesthesia of the cheek, nose, and upper lip. In the absence of any diplopia this can be followed safely by injection of concentrated alcohol, a drop at a time, up to a total of 1 cc. In the course of this infiltration the patient will complain of a burning sensation as the skin and mucous membrane of the upper jaw become completely numb.

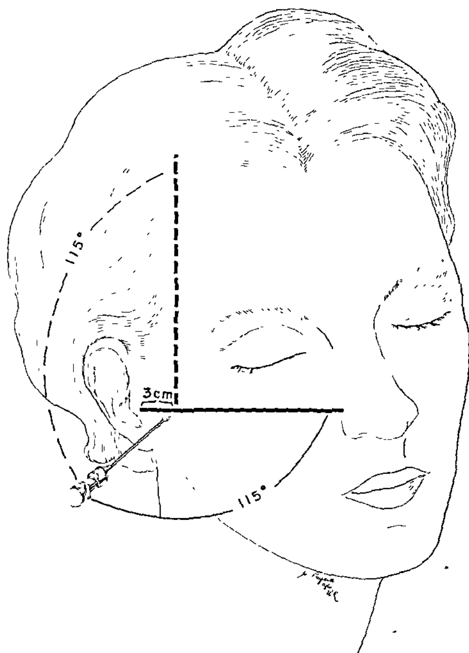


Fig 37 Superficial landmarks and bearings of needle for injection of maxillary nerve in pterygomaxillary fossa.

In a certain small proportion of skulls entrance to the pterygomaxillary fissure is blocked by an expansion of the pterygoid plate, so that injection of the nerve is impossible. In the majority of cases, however, the operator can feel his way into the fissure by working forward along the pterygoid plate. If the needle is pointed too far anteriorly it will meet the posterior bony wall of the maxilla. If difficulties are encountered in properly inserting the needle much assistance can be gained by checking its location by x-ray in the Waters position (Fig. 39).

Aside from puncture of the internal maxillary artery, the only risk comes from too deep insertion of the needle. This cannot occur except in unusually narrow skulls, if penetration is limited to 6.0 cm. in the female and 6.5 in the male. Beyond this point, however, contact may be made with the oculomotor, trochlear, or abducens as these nerves enter the superior orbital fissure slightly beyond and above the foramen rotundum or, at a slightly greater depth, with the optic nerve. When penetration of alcohol is slightly too deep, transitory diplopia from paresis of the abducens may result. When this has occurred the external rectus muscle has usually recovered.

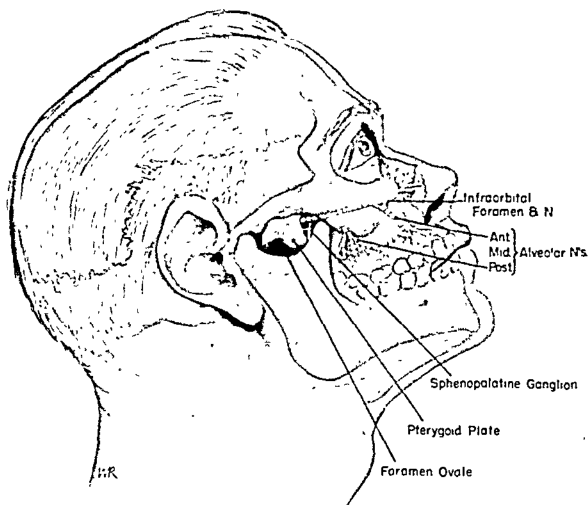


Fig 38 Anatomical relationships of the maxillary nerve from its exit from foramen rotundum.

3. Injection of the Supraorbital Nerve

There is no way to inject the first division of the trigeminus, as the nerve lies within the cavernous sinus and on its way to the orbit runs in close proximity to the motor nerves to the muscle cone of the eye. This is unfortunate, as the ophthalmic nerve carries most of the fibres which innervate the sensitive structures within the cranium (Penfield and McNaughton,

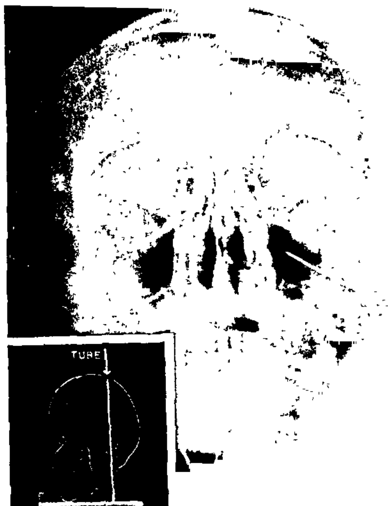


Fig. 39 Radiographic localization of needle in maxillary block. Insert shows position of skull and x-ray tube in Waters position for projection of sinuses and foramen rotundum.

1940) and it is therefore often implicated in conduction of pain in migraine and other obscure cephalalgias. However, its supraorbital branch, which supplies the skin of the medial forehead and scalp as far as the vertex, can easily be blocked for diagnosis and therapy of first division neuralgia as it emerges from the supraorbital foramen.

This foramen, or more often notch, can be palpated in the medial third of the orbital ridge (Fig. 40). All that is necessary is to insert a fine hypodermic needle into the notch. The tip should hug the bone and be inserted to a depth of 5 to 10 mm. Pain will be felt as the fibres of the nerve are touched. One may then gradually infiltrate up to 1 cc. of alcohol. This will cause a moderate degree of ecchymosis and swelling of the upper lid, but other complications are almost unknown. The nasal, infra- and supratrochlear, and lachrymal branches (Figs. 34 and 51), although easy to block by

infiltration of procaine across the brow ridge, are difficult to inject with alcohol. If these must be interrupted we advise operation rather than injection, since only in this way can all of these branches be interrupted with certainty.

4. Injection of the Infraorbital Nerve

The infraorbital emerges at the same distance from the midline as the supraorbital and mental nerves (Fig. 40). As the nerve passes through a distinct foramen below the lower rim of the orbit and not a notch, it cannot be identified by direct palpation. Nevertheless its site can be located by marking a point 8 to 10 mm. below the inferior orbital rim and in the same vertical line as the supraorbital notch. This foramen measures 2 to 3 mm. in diameter and the canal behind it runs upwards as well as backwards. With these directions in mind it is usually a simple matter to find its opening with the tip of the needle through the thin tissues of the cheek. The needle should, however, be inserted a good 2 cm. beneath the orbital rim and worked obliquely upwards until its tip lies within the foramen. Deeper insertion of the needle is to be avoided, as either the lower or upper walls of the foramen may be deficient so that the sclerosing agent injected at greater depths would be likely to leak into the antrum or the orbital cavity. Prior to injection the plunger of the syringe should always be drawn back to make sure that air is not aspirated from perforation of the antrum. A half to 1 cc. of 95 per cent alcohol is then injected, a drop at a time, until anaesthesia is complete. After making the injection it is advisable to make firm pressure against the skin around the needle in order to prevent the alcohol from diffusing subcutaneously and damaging motor fibres of the facial nerve to the muscles of the upper lip.

Injection of the supraorbital nerve will often suffice to interrupt ophthalmic neuralgia, as the pain is usually referred more to the forehead and scalp than to the orbit. In the case of maxillary neuralgia, however, so much pain is referred to the palate and teeth that anaesthesia limited to the cheek is of little help, except for its diagnostic value when proximal maxillary block within the pterygomaxillary fissure has not been feasible.

5. Injection of the Gasserian Ganglion

It is unfortunate that introduction of a needle through the foramen ovale is such a difficult procedure in the average hands and that injection of the ganglion is fraught with no little risk. The danger of injury to lower cranial nerves, however, need not be considered when procaine alone is injected in small quantity. It is only fair to add that in the hands of experts

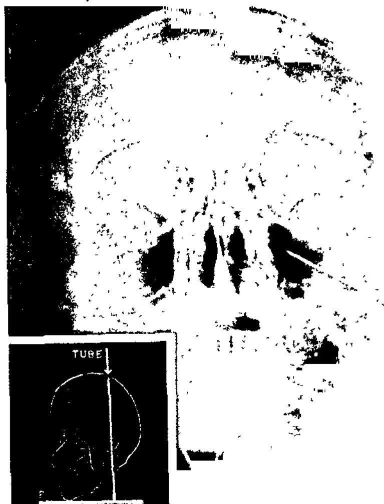


Fig 39. Radiographic localization of needle in maxillary block. Insert shows position of skull and x-ray tube in Waters position for projection of sinuses and foramen rotundum.

1940) and it is therefore often implicated in conduction of pain in migraine and other obscure cephalalgias. However, its supraorbital branch, which supplies the skin of the medial forehead and scalp as far as the vertex, can easily be blocked for diagnosis and therapy of first division neuralgia as it emerges from the supraorbital foramen.

This foramen, or more often notch, can be palpated in the medial third of the orbital ridge (Fig. 40). All that is necessary is to insert a fine hypodermic needle into the notch. The tip should hug the bone and be inserted to a depth of 5 to 10 mm. Pain will be felt as the fibres of the nerve are touched. One may then gradually infiltrate up to 1 cc. of alcohol. This will cause a moderate degree of ecchymosis and swelling of the upper lid, but other complications are almost unknown. The nasal, infra- and supratrochlear, and lachrymal branches (Figs. 34 and 51), although easy to block by

vessels, cavernous sinus, and circle of Willis pass through the ganglion and run principally in its first division, which is not accessible to diagnostic block at any other point.

In spite of the favourable results reported by Harris (1926), Härtel (1933), and certain French authors with alcoholic injection of the ganglion itself, few neurosurgeons with experience in the modern techniques of retrogasserian neurectomy and medullary tractotomy have elected to substitute this more difficult and less controllable method for obtaining permanent anaesthesia of the face. Yet the reasonable safety and advantages of diagnostic procaine block of this important sensory cell station are incontrovertible, so that the surgeon interested in developing the treatment of obscure neuralgias of the head will be wise to perfect himself in its technique.

Two principal routes are available for approach to the Gasserian ganglion. The lateral approach between the mandibular notch and zygoma was first described by Harris (1912), and shortly thereafter the more direct approach to the foramen in the base of the skull was developed by Härtel in 1914 and described especially clearly by him in 1933.

The lateral approach:—Harris's approach differs in no way from his method of reaching the mandibular nerve, except that it is of particular importance to insert the needle as far below the zygoma as possible. This is facilitated by opening the jaws widely with a dental prop and thereby lowering the mandibular ramus (Fig. 34). The foramen ovale points laterally as well as downwards in at least 25 per cent of cases according to Grant (1936) and with greater frequency according to Harris (1926). When the bony configuration permits, the needle is advanced with extreme care through the foramen an additional 0.5 cm. Bearing in mind the danger of puncturing the internal carotid artery within the cavernous sinus or of the solution's reaching the lateral cerebellar recess via the subarachnoid space which surrounds the root fibres as far as the Gasserian ganglion, the surgeon must never advance the needle to a greater depth than 5.5 cm. from the skin of the cheek. The surgeon with little experience of this particular injection would do well to attempt it only under x-ray control to ensure preventing the needle point from passing more than 6 to 7 mm. medial to the foramen ovale. Pollock and Potter (1916) were, we think, the first to describe the value of x-ray for this purpose. Everyone who plans to perform this injection should read Wilfred Harris's description in full (see pp. 205-217 of his book, 1926). We and other American surgeons with whom we have discussed this route of injection have too often met with difficulty in getting the needle tip through the foramen ovale The reason, as pointed out above, is that the foramen points downward and not laterally enough to permit its entrance from the side in a considerable proportion of cases.

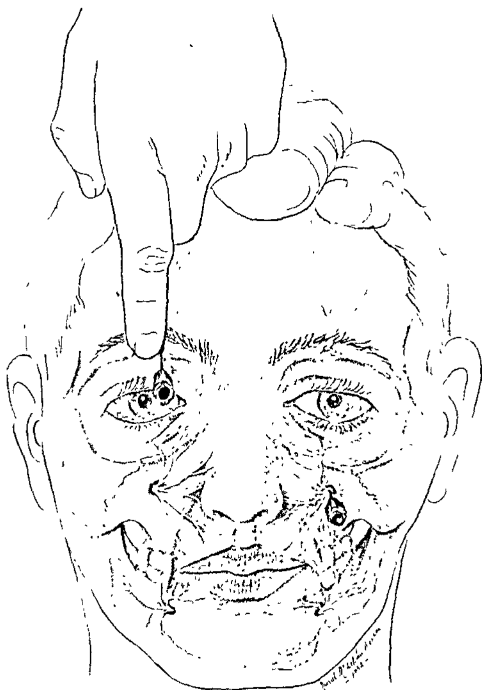


Fig. 40 Injection of supra- and infraorbital nerves

permanent block with alcohol has proven both feasible and relatively safe. This procedure is of particular value in senile, extremely poor-risk individuals and in diagnostic work for ascertaining whether cases of intractable migraine or other unusual cephalalgias can be relieved by partial retrogasserian neurectomy or intramedullary tractotomy of the descending root. The nerve pathways which conduct pain from sensory endings in the dural

(Figs. 34 and 41). The depth of the foramen will correspond to the distance to the tubercle of the zygoma, as both lie in the same coronal plane. Usually the needle impinges against the base of the sphenoid reasonably close to the foramen, and its exact relation to this structure can be ascertained by a film taken in the submentovertical position (Fig. 42). We have encountered considerable difficulty in making the slight adjustment of the needle



Fig. 41. Hartel injection of Gasserian ganglion
Technique of inserting needle through tissues of cheek so that its tip enters the ganglion through the foramen ovale.

It is, nevertheless, feasible in many instances to infiltrate the lower part of the Gasserian ganglion with alcohol merely by placing the needle in the mandibular division of the nerve at the foramen ovale, pointing the bevel upward and injecting a total of 2 to 4 cc. of alcohol. Hypalgesia appeared in the zones of the first and second divisions in 23 of 54 cases so treated. Usually the sensory loss outside of the third division lasted only a few days, but its presence suggested that the alcohol had penetrated to some of the cells of the Gasserian ganglion. This conclusion is borne out by the gratifying duration of the relief of pain. Of a series of 30 such patients with trigeminal neuralgia who have had late follow-up, the average duration of relief of pain was 30 months (Sweet, 1950).

Härtel's method:—When the needle is passed upwards from below there can be no obstruction to entering the 4 x 8 mm. foramen in the base of the sphenoid bone. Accurate manipulation of the needle through the foramen ovale is both time-consuming and painful, so that if the patient can be anaesthetized during this stage and then awakened at the time of the preliminary testing with procaine both the surgeon and his subject will benefit. This modification of Härtel's (1914) technique was suggested by Putnam and Hampton (1936) and made possible by radiological determination of the needle's position. When Putnam did his preliminary injections in this hospital he used intravenous N-methylcyclohexenyl-methylmalonylurea (Evipal) and the complete injection was carried out on the unconscious patient. With recent advances in anaesthetic technique it is possible to keep the patient asleep and quiet with a light intravenous dose of sodium pentothal and then to awaken him at the desired moment with 100 mg. of Metrazol if spontaneous recovery is too long delayed. We have used this extensively in the course of operations like cordotomy, where it is of great advantage to make sure that the spinothalamic tract has been cut to a sufficient depth.

The technical steps in this injection are a modification of the procedure described by Härtel. With the patient on the x-ray table, the surgeon inserts his left forefinger into the patient's mouth to palpate the last upper molar tooth and the ascending ramus of the mandible. A 10 cm. 19-gauge lumbar puncture needle (a fairly rigid shaft is desirable), with depth marker set at 6 cm. from its tip, is passed through the skin opposite this tooth and worked upwards within the tissue of the cheek medial to the mandibular ramus. Contamination of the needle by penetration of the mucosa is prevented by digital guidance and the hand withdrawn and glove changed once its tip has passed beyond the oral cavity.

The bearings for the line of insertion of the needle are the mandibular tubercle of the zygoma from the side and the pupil of the eye from in front

necessary to enter the foramen, as at this depth it is not possible to make even minor corrections without partial withdrawal and reinsertion. When this is done repeat x-rays are all too likely to show that its tip has been shifted from one lip of the foramen to the other. It is therefore better to adopt Putnam and Hampton's suggestion of inserting a second needle alongside the first and attempt to adjust its course to the exact deviation indicated on the film.



B. Lateral film with needle in position shown in A.

C. Lateral film with needle inserted 5 mm. further so that its tip has passed through the foramen.

The needles have been retouched to bring out their position in relation to the dense bone at the floor of the skull.

The needle can usually be felt to sink through the foramen and there is often a distinct twitch of the lower jaw from stimulation of the motor root. The needle should be pushed 5 mm. into the foramen and the position of its tip just inside the inner table of the skull confirmed by lateral x-ray. Electrical stimulation by means of the Selverstone needle insulated except at the tip should be an added help in establishing the exact position of the tip within the Gasserian ganglion. After it has been ascertained that neither blood nor spinal fluid can be aspirated, 0.25 to 0.5 cc. of 2 per cent procaine is injected and the patient awakened with intravenous Metrazol. Minor adjustments of the needle and additional injection of procaine in small amounts can then be made until complete anaesthesia is obtained. If alco-

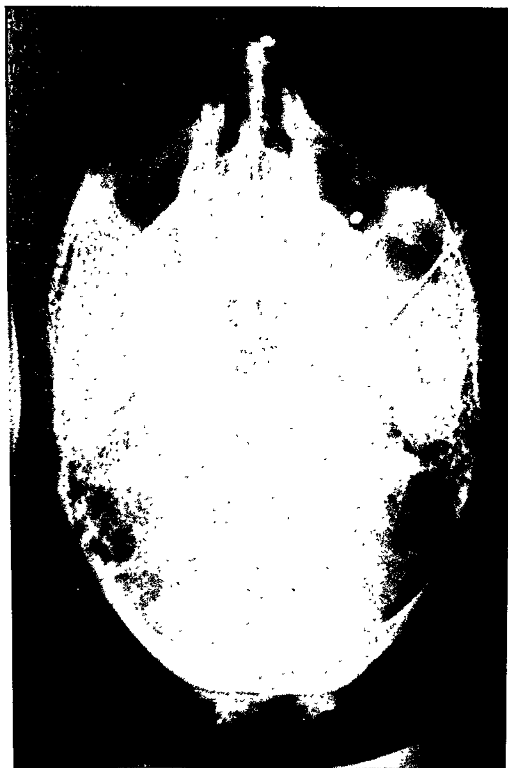


Fig. 42 Injection of Gasserian ganglion.
A. Submento-vertical film showing needle tip at orifice of foramen ovale

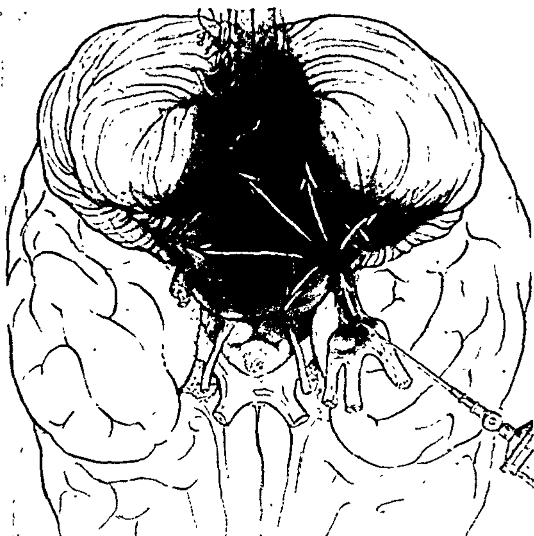


Fig. 43. Dandy's diagram to illustrate the danger of the injection of alcohol into the Gasserian ganglion.

The alcohol may be "injected into the cerebrospinal fluid surrounding the ganglion and immediately passes to the base of the brain, causing a dreadful series of paralyses of all the nerves on the side of the injection, in addition to pronounced disturbance of the cerebellum."

Figure and quotation from Dandy: *Arch. Surg*, 1929A. Courtesy, American Medical Association, Chicago.

hol is to be used for permanent block extreme precautions must be taken to ensure that the sclerosing fluid is injected within the dural sheath of the ganglion and that none escape into the subarachnoid space.

Penman (1949) gives in meticulous detail the technique of inserting the needle to ensure injection of alcohol into the substance of the Gasserian ganglion. This is carried out under x-ray control (special oblique and basilar projections) so that its tip will enter the centre of the foramen ovale and can then be slipped an added 10 to 15 mm. into the plexus triangularis (that portion of the root immediately behind the ganglion). He points out that this flat ganglion is only 2 or 3 mm. in thickness and that the needle, in order to lie within its sheath, must not only enter the skull through the centre of the foramen but parallel to the slope of the petrous ridge. This procedure necessitates a special oblique film with the rays passing between the maxilla and the ramus of the mandible so that they travel at an acute angle with the needle. By this special position the operator can visualize the depth of penetration and the needle's inclination to the petrous ridge. He can also make sure that the needle does not merely skirt the nerve sheath and avoid its insertion between the skull and dura or above the dura. This description will be found extremely helpful for anyone who intends to inject the ganglion with alcohol. Its injection with sclerosing solutions seems to us less certain* and more dangerous than surgical section of the Gasserian root. On the other hand, diagnostic blocking of the ganglion with procaine is extremely useful in deciding whether operation is justified in certain unusual neuralgias. If procaine is used, which diffuses more freely than alcohol, it is only necessary to manipulate the needle so that its tip barely penetrates the floor of the skull. Under these circumstances the relation of the needle tip with the foramen can be determined by a film in the standard submentovertical position and its penetration to the inner table of the skull by a simple lateral film.

The precautions necessary to guard against injection within the root sheath above the ganglion cannot be overemphasized. Such a complication should not occur if the needle does not enter the skull too deeply, but fluid injected into the subarachnoid space will spill over the petrous tip and diffuse into the lateral cistern and bathe the cranial nerves in the cerebellopontine angle (Fig. 43). Small amounts of procaine reaching this region will cause only temporary paresis of the sixth, seventh, eighth, and

*For the difficulties encountered in attempts to secure an effective block of the entire ganglion, see accounts in Harris's and Penman's articles. No doubt more complete destruction of the sensory fibres can be achieved by Penman's method, but we are reluctant to advise such deep insertion of the needle as is required for injection of alcohol into the plexus triangularis. Here its tip will lie altogether too close to the point of free communication with cerebrospinal fluid within the root sheath.

CHAPTER VI

PERIPHERAL NEURECTOMY

A. PREVENTION OF RE-FORMATION OF NEUROMATA

Effective technical methods for excising and preventing the re-formation of neuromata, which play a part in so many painful states, are urgently needed. A number of simple and apparently foolproof procedures were devised by military surgeons in World War II and proved to be effective on experimental animals. These are so simple and free from complications that they deserve continued further trial, but from past experience with their use we cannot claim that any are really effective in solving the problem of recurrent neuroma formation.

Most surgeons in performing an amputation have found it best to cut the nerve trunks high and let them retract into a bed of healthy muscle. However, once a painful neuroma has formed, it is advisable to try one of the following methods for its permanent eradication.

1. Chemical Injection

Absolute or 95 per cent ethyl alcohol was formerly used for this purpose, but has been shown by Guttmann and Medawar (1942) to be most ineffective. The transitory interruption of nerve conduction following injection of alcohol is clearly seen after blocking the branches of the trigeminal nerve. Smithwick and White (1935) found that the tibial nerve also regenerates rapidly and completely after 0.5 cc. of alcohol is injected directly within its trunk. To correct this Guttmann and Medawar suggested using more powerful protoplasmic poisons and proposed 10 per cent formalin or the solution of gentian violet used in bacterial stains. While these are more effective than alcohol, regeneration can none the less take place, as shown in Figure 44.

2. Burial of Nerve End in Contiguous Bone

Boldrey (1943) proposed drilling the shaft of a phalanx or other nearby bone and drawing the freshened nerve end into the hole, so that it would be trapped and compressed in bone laid down by periosteum (Fig. 45). This appears to be the simplest and most logical method of dealing with small nerves associated with convenient bones We have tried it in a num-

possibly other cranial nerves. Diplopia, facial weakness, and vertigo are effective danger signs, provided the patient is conscious and they are looked for. The danger of alcohol's reaching this area is obvious and Harris (1926) cites an instance where serious bilateral palsies were produced in this fashion. Härtel (1933) in his extensive experience with 173 of these injections had two complicating facial palsies and 18 transitory pareses of the abducens nerve.* The motor root of the fifth is nearly always weakened, but tends to recover. Another serious objection to alcohol is the tendency to relapse, which occurred in 23 per cent of Härtel's cases. We have therefore confined our ganglionic injections to diagnostic tests with procaine. Possibly our attitude on this score is over-conservative. We would certainly be willing to inject the ganglion with alcohol in an elderly, poor-risk patient, provided that peripheral extracranial block had been tried and failed to control intolerable pain.

---

*Kirschner (1931) and Philippides (1947) have advocated destruction of the ganglion by coagulation with a needle electrode introduced through the foramen ovale by means of a mechanical guide. This method, according to Tonnis and Kreissel (1951), has also been followed by a high rate of paralytic keratitis, damage to neighbouring cranial nerves, and distressing anaesthesia dolorosa These authors state that electrocoagulation, as well as alcohol injection of the Gasserian ganglion, is too dangerous and should be abandoned altogether

ber of digital and intercostal neuralgias and intend to continue to do so, but cannot claim that it is invariably successful.

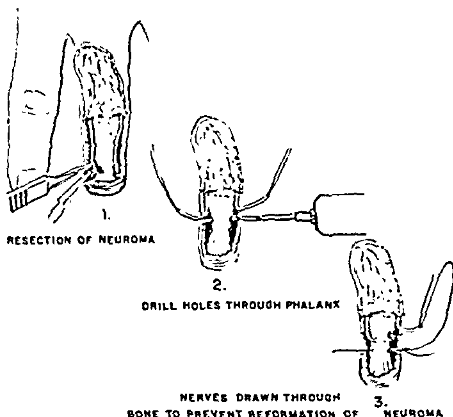


Fig. 45. Prevention of neuroma formation by drawing cut end of nerve through drill hole in neighbouring bone, as suggested by Boldrey (1943).
From White: *U. S. Nav. Med. Bull.*, 1945. Courtesy, Bureau of Medicine and Surgery, Navy Department, Washington, D.C.

3. Burial of Nerve End in Nonirritant Alloplastic Cap

The nerve stump can also be enclosed in a snugly fitting cap to prevent outgrowth of neurofibrils. Smithwick (1940) attempted to prevent regeneration of the thoracic sympathetic chain by burying its upper end in a silk sleeve tied at its end. This has proved ineffective because regeneration has occurred, and at secondary exploration the fine silk mesh has been found to have been absorbed and replaced by a mass of scar tissue. During World War II Spurling (1943) as well as White and Hamlin (1945) substituted the use of sleeves of 0.5 mil tantalum. By a terminal ligature the nerve end is drawn into the sleeve previously rolled to a snug fit and fixed therein by crushing, folding over, and recrushing the end of the tube (Fig. 46). W. V. Cone (personal communication) has recently simplified this method still further by using polyethylene plastic tubing. This is as non-



Fig 44. Neuroma following injection of formalin

Eighteen months previously this ulnar nerve had been injected with 1 5 cc of 40 per cent formalin to relieve severe dysaesthesia in the cutaneous area. After two months pain gradually returned At 18 months, when this biopsy was taken, pain conduction with over-response was present Motor paralysis, which was present prior to injection, remained unchanged The photomicrograph shows extreme interstitial fibrosis, but fascicles bound in scar appear to be in good condition

When a sensitive neuroma can be palpated and relief follows its direct infiltration with procaine, we advocate a single trial of excision combined with one of the above procedures to reduce the chance of re-formation. If this occurs, as will often be the case, little is lost as long as the surgeon refrains from further resections and particularly from extensive proximal neurectomy, as this is certain to prove a useless procedure. Under these circumstances the patient must either learn to get along with his discomfort or undergo one of the more radical procedures listed below.

B. TEMPORARY DENERVATION OF EXTREMITIES FOR PAINFUL GANGRENE

In 1930 it was shown by Smithwick and White that "extremities which hitherto have been . . . doomed to amputation because of indolent, sensitive, painful ulcerations, can often be saved if the pain factor is eliminated for a sufficient length of time to give conservative procedures a chance to take effect." Five years later the same authors (1935) published results in 45 cases of actual or threatened gangrene in thromboangiitis obliterans or arteriosclerosis with very severe pain. Amputations limited to toes or metatarsal heads became feasible when pain and reflex vasoconstriction were eliminated and effective local measures could be instituted. As a result, the percentage of major amputations in this group was considerably reduced. The intervening years have more than borne this out, as recently acknowledged by Shumacker (1948B).

The anatomical arrangement of the peripheral nerves in the leg is peculiarly well adapted to this procedure, as some (saphenous and sural) are purely sensory and the mixed nerves (tibial, superficial and deep peroneal) give off no vitally important motor branches in the inferior third of the leg. If desired, complete anaesthesia of the lower half of the leg and foot can be obtained with the sacrifice of little in the way of motor function except the relatively unimportant intrinsic muscles of the foot. It is, however, important that only a temporary denervation be performed in order to avoid the late trophic disturbance. Years ago the veterinarians hit on the method of "nerving," whereby a hopelessly lame horse suffering from laminitis (periostitis of the terminal bone in the hoof) could be made to appear as a sound animal. Unfortunately the hoof often breaks down and the horse then has to be destroyed. Clinical experience has shown that if the nerve trunks are simply crushed in a haemostat six inches above the ankle the incisions will heal and good regeneration will take place within a period of from three to six months.

The technical steps are illustrated in Figure 47. The nerves are exposed through short incisions under local anaesthesia. It is best not to attempt

irritant as tantalum, comes in a large variety of sizes, and its end can easily be sealed by crushing between the heated blades of a haemostat. These methods are suitable for larger nerve trunks, and there is evidence that they prevent formation of end-bulb neuromas in the area enclosed within the metallic cap. Nevertheless, as shown in Chapter XII, the pain associated with this lesion is rarely relieved.

For small nerves, painting their stumps with a solution of 10 per cent methyl methacrylate dissolved in acetone, as suggested by Edds (1945), seems to be the most logical method yet proposed. Acetone is a strong

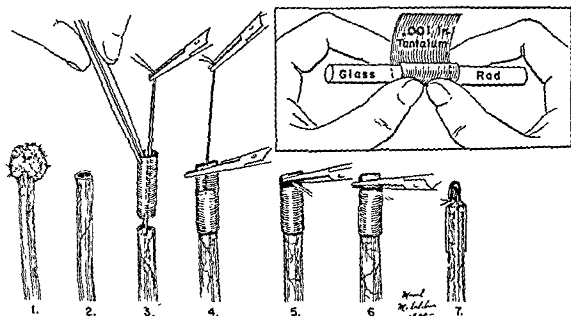


Fig 46 Prevention of neuroma formation by covering end of nerve with tantalum cap. This method was advocated by White and Hamlin (1945). (1) and (2), resection of painful end-bulb neuroma, (3), the amputated end of the nerve is transfixed by a fine silk stitch and covered by a sleeve of tantalum, (4), the open end of the sleeve is crushed in a haemostat, (5), (6), and (7), the flattened end is turned back on itself and crushed again, thereby fixing it firmly to the end of the nerve.

From White and Hamlin *J Neurosurg.*, 1945, by permission of the editor.

protoplasmic toxin, and the resultant impervious Lucite cap is nonirritating to surrounding tissue and should be an effective barrier to the prolifera-tion of axones.

The final answer to these methods was not obtained in the recent war, but their further use is recommended in appropriate circumstances because we have nothing better to propose. Although they have proved capable of preventing the re-formation of the typical end-bulb neuroma with twisting axis cylinders compressed and presumably poorly oxygenated in scar tissue, we have nevertheless seen numerous instances where hyperaesthesia, deep tenderness, and pain have recurred after a period of several months.

C. NEURECTOMY IN PAINFUL ARTHRITIS OF HIP

Post-traumatic arthritis of the hip and also the degenerative that comes with old age (malum coxae senilis) may be accompani severe pain on movement and muscle spasm. Denervation is a cours last resort when reconstruction of the joint cannot be safely undertak. The two principal nerves that innervate the joint are the obturator and a branch from the sciatic that also supplies motor control to the quadratus femoris and inferior gemellus. Division of the obturator will relieve painful adductor-flexor spasm, but even when both nerves have been divided pain is not usually completely relieved for long. The reason for this is that a branch of the femoral and possibly other nerves as well reach the joint and its capsule. We have found division of the obturator to be the most important, particularly when there is distressing adductor flexion of the thigh.

1. Obturator Denervation

This nerve is most easily exposed intrapelvically on the inner aspect of the pubic ramus where it pierces the obturator fascia to enter the groove in the under surface of the bone. Local infiltration anaesthesia is very satisfactory. A 5 cm. incision is made superficial to Poupart's ligament corresponding to the exposure employed for hernial repair, or the Pfannenstiel type of transverse suprapubic incision, as recommended by Chandler and

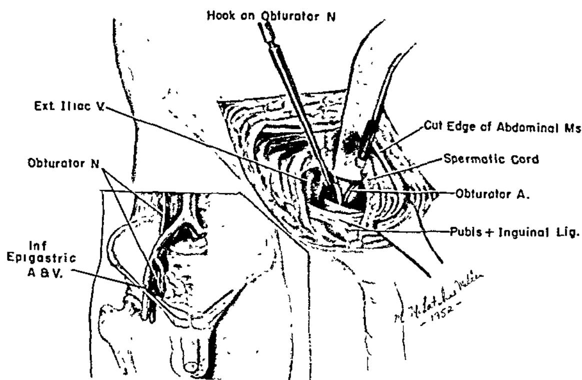


Fig. 48. Surgical exposure for intrapelvic neurectomy of obturator nerve.

too extensive a denervation at a single stage, but to expose and crush the tibial nerve first and then the superficial and deep peroneal branches a few days later. At times either the saphenous branch of the femoral nerve and/or the sural nerve take an unusually extensive share in the innervation of the foot. When anaesthesia of the foot fails to ensue after crushing of its three principal nerves, it is necessary to deal with one or both of these other nerves, depending upon the zone which still retains sensation. Crushing the nerves about 15 cm. above the malleoli causes no

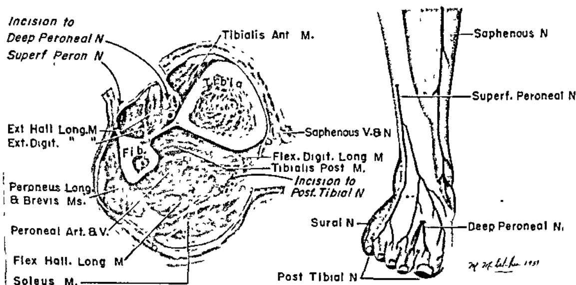


Fig 47. Crushing peripheral nerves for relief of pain in obliterative vascular disease of lower extremity.

Surgical exposure of nerves in lower leg and their superficial sensory distribution.

recognizable paralysis, except in the intrinsic muscles of the foot. With precautions to preserve collateral circulation very few complications have been observed.

This procedure is less well adapted to the hand on account of the importance of the intrinsic musculature. Fortunately painful gangrene of the fingers is much rarer than in the toes. We have, however, been forced to denervate the fingers exclusive of the thumbs in a woman suffering from extremely painful patches of terminal gangrene associated with an unusual variety of scleroderma and subacute bacterial endocarditis. Transverse incisions were made under local anaesthesia in the distal flexion crease of each palm and the digital nerves to the four medial ischaemic fingers crushed. This patient was immediately relieved of her excruciating pain, was able to rest and sleep without her former heavy medication, and the incisions were healing uneventfully when thrombi on her aortic valve broke off and led to death from cerebral embolism (See Chapter XIII, p. 426).

direction to enter the obturator foramen. As it is cut the thigh will be seen to flex as well as adduct.

2. Section of Sciatic Sensory Ramus

The patient is placed in a lateral-oblique or prone position on the operating table, with the hip as slightly flexed as the comfort of the patient and mobility of the joint permit. Either spinal or general anaesthesia may be used. A generous incision is made along the line connecting the posterior superior spine of the ilium with the great trochanter. When the fibres of the gluteus maximus muscle have been divided and spread apart, the sciatic nerve will be seen emerging from under the piriformis muscle. The nerve is gently freed and elevated from its bed with a sling of rubber dam. It is then easy to identify the articular ramus as it leaves the deep surface of the sciatic trunk and courses downward beneath the gemelli and obturator internus to end in the quadratus femoris muscle and capsule of the hip joint, as shown in Figure 49. It is best to prove its identity by electrical stimulation and observation of contraction of the gemellus inferior and quadratus femoris muscles. Several centimetres of the ramus are resected and the incision closed.

Seidler (1939) in their excellent description of this operation, if both obturator nerves are to be cut at the same time. One exposes the superior surface of the ligament, dividing the fascia and attachments of the lateral abdominal muscles, then retracting these muscles and the spermatic cord upwards. The deep epigastric and external iliac vessels are next identified in the lateral angle of the incision as the peritoneum is freed by blunt dis-

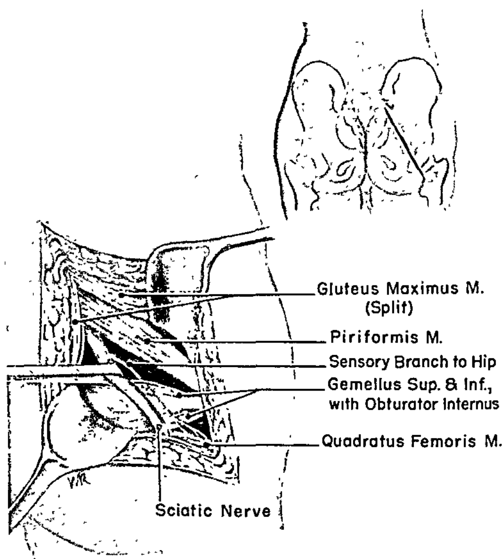


Fig. 49 Surgical exposure of sciatic sensory ramus to hip joint

section from the pubic ramus (Fig. 48). It is an easy matter to identify the obturator groove by digital palpation. If a lighted retractor is then inserted to retract the peritoneum, the nerve and its accompanying artery are readily identified. The nerve comes up from the depths and from a lateral

understand these limitations, as well as the limited but clear-cut indications for this operation.

A. TECHNIQUE OF POSTERIOR SPINAL ROOT SECTION

Since the roots which innervate a given painful area are usually well known and cutting their sensory fibres is so painful, it is generally best to operate under general anaesthesia.* It is, however, vital for the surgeon to know exactly which roots he is cutting. Because an error of at least a single vertebra is often made if one attempts to identify the spinous processes by palpation, it is best to avoid possible mistakes by exact radiographic control. We do this as a preliminary step in the operation by tapping a sterile heavy pin (a steel phonograph needle serves this purpose well) into a given spinous process and taking a lateral x-ray. The field is then prepared and the incision made, so that the marked spinous process can be exposed before the pin is removed. For an ordinary thoracic rhizotomy it is simplest to operate with the patient prone, but we prefer a semilateral position in patients with coronary disease and angina pectoris or others with poor cardiac or pulmonary reserve, and the upright cerebellar headrest for upper cervical laminectomy.

The muscles are separated from the spinous processes and laminae by scraping them clean with a sharp periosteal elevator. If for any reason blood loss must be kept to an absolute minimum, the electro-cutting scalpel set with a maximal coagulating effect may be substituted. In any event, strict adherence to the bony surfaces will avoid excessive bleeding (Figs. 50 A and B). After they have been separated by a self-retaining retractor, the appropriate spines are cut and laminae rongeured away. The dura and arachnoid are then opened and the edges held apart by guy sutures. When care has been taken with the bony exposure, it is a simple matter to identify the roots by following them down to their foramina of exit from the spinal canal. In the rare circumstances where posterior rhizotomy must be undertaken in the lumbosacral region, this requires a more extensive laminectomy than if the roots were picked up where they emerge from the conus medullaris, but we know of no other accurate way of differentiating the contiguous sensory rootlets at this latter level. In the few cases in which we have performed a sacral rhizotomy we have been able to identify and preserve the anterior roots by stimulation and observation of the resultant motor contraction. In the cervical and upper thoracic segments of the cord, where the fibres leave at a less oblique angle and form discrete roots, there is no difficulty in locating the exact ones and cutting the posterior division before it joins its motor component.

*If local anaesthesia is preferable for any reason, we have found that the posterior roots can be rendered insensitive by brief application of a cotton pledget soaked in 2 per cent procaine.

CHAPTER VII

POSTERIOR RHIZOTOMY: SECTION OF THE SPINAL AND CRANIAL SENSORY ROOTS, OTHER CRANIAL NEURECTOMIES, AND MEDULLARY TRACTOTOMY OF THE DESCENDING TRIGEMINAL ROOT

INTERRUPTION OF POSTERIOR SPINAL and the equivalent cranial sensory roots is a procedure of proven value for relief of a number of classical (trigeminal and glossopharyngeal) cephalalgias and certain forms of otherwise intractable disease which give rise to pain in limited areas. These are described in Chapters XIV, XV, and XVI. Various numbers of spinal sensory roots must be interrupted to relieve the pain of malignant disease of the chest with invasion of the parietal pleura, and the upper four or five thoracic may be cut in angina pectoris. In these conditions and in carcinoma which involves the upper cervical plexus this operation is generally successful. However, when the brachial plexus is invaded by malignant cells or its peripheral divisions are caught in amputation neuromata, rhizotomy nearly always fails. In the atypical facial and postherpetic neuralgias failure has been almost invariable. Why pain should persist in the numb area and why it can often be relieved by interruption of the secondary neurones in the spinothalamic tract remains unknown. Some have tried to explain this on the basis of pain transmission over anterior spinal roots. Our attempts to relieve residual pain of this sort by additional section of the motor roots have never succeeded, and our experiences with stimulation of the central ends of these roots in the course of operations under local anaesthesia have shown that pain is only very occasionally evoked at relatively low voltages (see pp. 34-36).

In contrast to the analgesia and athermaesthesia after anterolateral cordotomy, total anaesthesia follows posterior rhizotomy. In the head or torso the resultant numbness is generally not very troublesome. In the case of the extremities, however, the totally deafferented limb is lost in space and as good as useless, even though muscular strength is preserved with intact anterior roots. Attention has been called to the importance of *sensation* in motor function by Gooddy (1949). Similarly, in the case of the bladder, the desensitized viscus is incapable of emptying urine, so that a condition similar to the tabetic bladder is produced. It is important to

end with a fine silk tie and secure the distal end with a dural clip to prevent any bleeding after the intervening segment is cut. The metallic clips are also excellent markers for subsequent roentgenographic verification of the exact extent of rhizotomy. After all the necessary roots have been cut the dura should be closed with a watertight running silk stitch. The muscles, fascia, and skin are then approximated with multiple layers of fine silk or stainless steel sutures.

B. OPERATIONS ON THE TRIGEMINAL NERVE

Pain from carcinoma of the orbit, maxilla, mandible, and other areas supplied by the trigeminal nerve can be relieved by section of the Gasserian root, but as cancer of the tongue and nasopharynx usually invades tissues innervated by the glossopharyngeal, or the upper cervical nerves in the case of metastases in the neck, it is often best to expose the trigeminal root in the cerebellopontine angle. With this approach the upper cervical sensory roots can be divided at the same time. When pain is felt deep in the ear we have found it advisable to cut the nervus intermedius as well as the glossopharyngeal, and also to divide the upper sensory rootlets of the vagus. Tarlov (1940) has shown that these latter are sensory filaments and they can be cut without risk of paralysis. However, if the vagus is seriously involved, as may be suspected whenever there is pain on swallowing, even such an extensive combined procedure will usually fail (see p. 503). The entire vagus cannot be sacrificed, because if this is done the patient will often succumb to bronchopneumonia secondary to difficulties in swallowing and inhalation of fluid.

The commonest and most definite indication for retrogasserian neurectomy is classical tic douloureux, but this operation will usually fail in cases of atypical facial neuralgia. It is almost certain to fail in postherpetic neuralgia. In the treatment of certain very old and feeble individuals who cannot tolerate any major operation, or in a few other cases where alcohol block has failed and it is desirable to observe the effect of temporary denervation, the supra- and infraorbital nerves may be avulsed at their foramina of exit from the skull. Both of these minor operations can be carried out with very little discomfort under local procaine infiltration. The relief unfortunately is only of short duration, as these nerves will as a rule regenerate in about six months.

1. Supraorbital Neurectomy

This nerve emerges from the supraorbital foramen. This is usually not a complete ring but rather a notch in the bone of the orbital ridge situated 2.5 cm. lateral to the glabella and easily felt with the finger. The incision

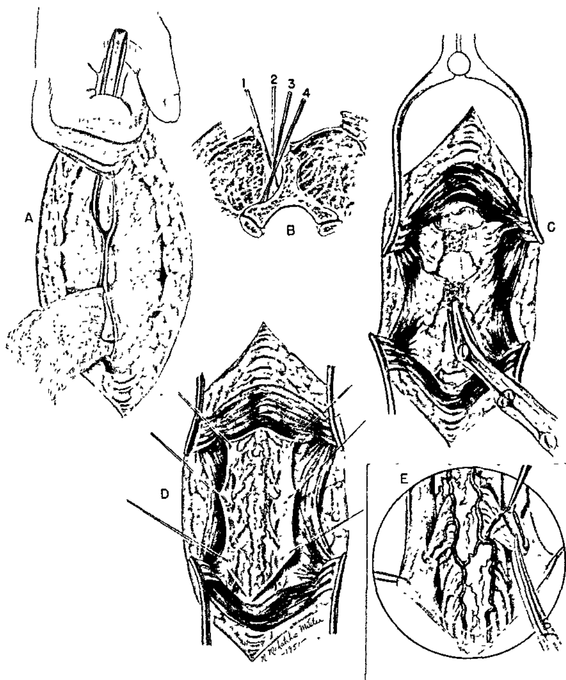


Fig 50. Posterior rhizotomy Technique of operation at cervical level.

When they are to be cut bilaterally every effort must be made to preserve accompanying blood vessels of any size, as focal ischaemia with spinal paralysis has resulted when too many of these collaterals have been sacrificed (Fig. 50 E).* Prior to cutting the delicate rootlets, we ligate the central

*Alexander and Kennedy (1939) reported an unusual complication, myelomalacia following intended division of T4 to T8 posterior roots. At autopsy it was found that part of the anterior roots from T4 to T7 had also been destroyed. Although the identification of the posterior roots is simple, the procedure must not be performed casually.

several centimeters avulsed by pulling it out of the foramen. After bleeding has been controlled the mucous membrane is closed with fine catgut sutures.

3. Retrogasserian Neurectomy by the Temporal Approach

The subtemporal approach to the ganglion and its posterior root is best carried out in the upright position so that blood and spinal fluid will drain away and not obscure the operative field. The patient can be held in position either in a dental chair or an upright cerebellar headrest. We prefer the latter, as the lower extremities can be elevated and any fall in blood

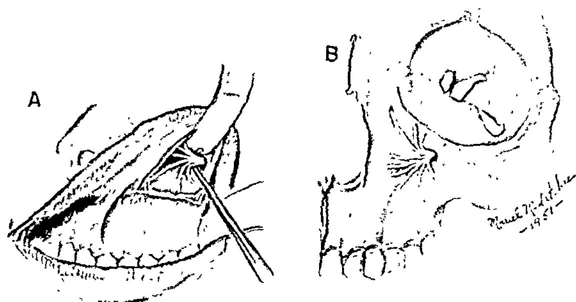


Fig. 52. Infraorbital neurectomy.

pressure better controlled. Either procaine infiltration or intratracheal ether gives satisfactory anaesthesia, but if local is used the patient will suffer considerable pain from manipulation of the sensory fibres along the middle meningeal artery, as well as of the ganglion itself and its sensitive root. With a little patience one can block these stimuli by applying a cotton pledget soaked in 2 per cent procaine to the artery for a few minutes, later by injecting the mandibular root and the ganglion itself when these structures are exposed.

An incision 2 cm. in front of the external auditory meatus is carried 5 cm. vertically upwards from the zygoma (Fig. 53) It is unsafe to prolong the

should be made just above the hair line of the eyebrow to avoid a visible scar and the hair should not be shaved, lest it fail to grow back properly and leave an unsightly deformity. On retracting the edges of the incision, it is a very simple matter to grasp the supraorbital nerve as it emerges from the notch or foramen with a haemostat and avulse it (Fig. 51). The trunk is usually torn off a centimeter or two within the orbit. Search should be made for a separate ramus frontalis. By continuing the incision to the medial portion of the eyebrow the supratrochlear nerve can be picked up and dealt with in similar fashion, but it is not generally feasible to identify the infratrochlear or nasal branches of the nasociliary nerve or the lateral cutaneous twigs from the lachrymal branch

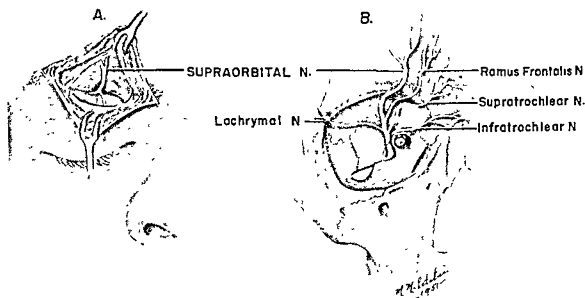


Fig 51. Supraorbital neurectomy.
In A, the supraorbital branch and ramus frontalis are shown as a single nerve, in B, as separate structures.

2. Infraorbital Neurectomy

This structure leaves the skull through an aperture which lies 8 to 10 mm. below the lower rim of the orbit and at exactly the same distance from the midline as the supraorbital foramen. In an old and debilitated individual with poor capacity for healing it may be most easily exposed by a 2 cm. transverse incision in the cheek. In younger individuals such a visible scar can be avoided by retracting the upper lip and incising the mucous membrane over the maxilla at its apex above the alveolar ridge (Fig. 52). The foramen and nerve are easily exposed by elevating the periosteum upwards from the maxilla. The nerve is grasped in a haemostat and a length of

incision any lower than this, as the uppermost branches of the facial nerve lie just beneath the zygoma. The branches of the superficial temporal artery are ligated or coagulated, and the temporal muscle is split in the plane of its fibres. A burr opening is then made in the bone and the thin temporal squama rongeured away over an area about 4 cm. in diameter. This should be carried down to the floor of the middle fossa in order to obtain the most direct view beneath the temporal lobe dura. If zygomatic air cells are opened they should be plugged with bone wax. The dura is then stripped centrally from the floor of the skull. Freeing it up with a tuft of cotton on a Hartmann forceps is usually a simple procedure, but in elderly individuals or in those who have had numerous injections of alcohol it may be difficult and in places it may require sharp dissection. In rare instances bony spurs in the floor of the skull may interfere with exposure enough to require chipping them away with an osteotome. The line of approach is directly inwards at right angles to the long axis of the skull, and the dura should be freed from the anterior slope of the petrous ridge and forward some 3 cm. The temporal lobe dura is elevated by a lighted retractor held in the operator's left hand or at times, when both the surgeon's hands must be free, by his assistant. Operating in a darkened room is a great help, as then all the light can be focused on the operative field.

At the foramen spinosum the dura is firmly attached to the underlying bone by the middle meningeal artery (Fig. 53E). The foramen must now be firmly plugged with a tiny tuft of cotton introduced by an angulated dental forceps, as illustrated in figure 53F. The emerging trunk of the middle meningeal artery is then coagulated and cut. This protects against any risk of subsequent arterial bleeding. After the artery has been cut the dura usually strips with ease, revealing the mandibular root entering the foramen ovale. This lies slightly anterior and medial to the foramen spinosum. The temporal lobe dura must now be freed from the dura propria which forms the epineurium of the mandibular root, the covering of the ganglion, and its root sheath. A line of cleavage can be developed by blunt dissection so that the mandibular and maxillary nerves are exposed in turn and then the ganglion. It is important, as the dura is freed posteriorly from the anterior slope of the petrous ridge, to be on the look-out for the great superficial petrosal nerve. This emerges from a tiny foramen (hiatus Fallopii) in the temporal bone just lateral to the Gasserian ganglion and then passes beneath it (Fig. 62). It must not be avulsed. This can be avoided by leaving the dura attached to the skull at this point. Traction on this nerve, which is a branch of the facial, may cause secondary swelling of the facial, which is then compressed within its tight bony canal. Injury to the great superficial petrosal nerve may result not only in facial palsy, but in injury to the lachrymal fibres which run in the petrosal nerve. The resultant

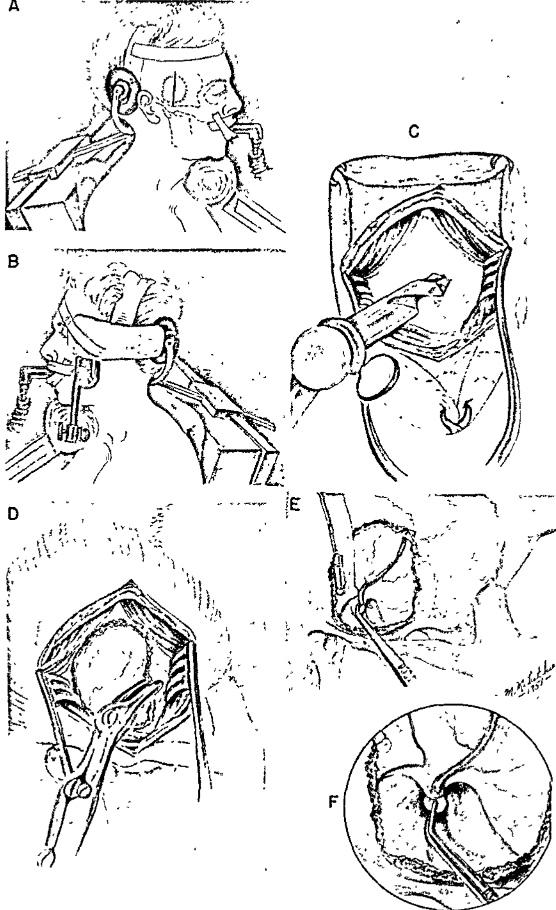


Fig 53. Retrogasserian neurectomy, subtemporal approach.
A. and B. Position of patient and incision.
C. and D Bony opening in temporal squama
E. and F. Control of middle meningeal artery by plugging foramen spinosum with

incision any lower than this, as the uppermost branches of the facial nerve lie just beneath the zygoma. The branches of the superficial temporal artery are ligated or coagulated, and the temporal muscle is split in the plane of its fibres. A burr opening is then made in the bone and the thin temporal squama rongeured away over an area about 4 cm. in diameter. This should be carried down to the floor of the middle fossa in order to obtain the most direct view beneath the temporal lobe dura. If zygomatic air cells are opened they should be plugged with bone wax. The dura is then stripped centrally from the floor of the skull. Freeing it up with a tuft of cotton on a Hartmann forceps is usually a simple procedure, but in elderly individuals or in those who have had numerous injections of alcohol it may be difficult and in places it may require sharp dissection. In rare instances bony spurs in the floor of the skull may interfere with exposure enough to require chipping them away with an osteotome. The line of approach is directly inwards at right angles to the long axis of the skull, and the dura should be freed from the anterior slope of the petrous ridge and forward some 3 cm. The temporal lobe dura is elevated by a lighted retractor held in the operator's left hand or at times, when both the surgeon's hands must be free, by his assistant. Operating in a darkened room is a great help, as then all the light can be focused on the operative field.

At the foramen spinosum the dura is firmly attached to the underlying bone by the middle meningeal artery (Fig. 53E). The foramen must now be firmly plugged with a tiny tuft of cotton introduced by an angulated dental forceps, as illustrated in figure 53F. The emerging trunk of the middle meningeal artery is then coagulated and cut. This protects against any risk of subsequent arterial bleeding. After the artery has been cut the dura usually strips with ease, revealing the mandibular root entering the foramen ovale. This lies slightly anterior and medial to the foramen spinosum. The temporal lobe dura must now be freed from the dura propria which forms the epineurium of the mandibular root, the covering of the ganglion, and its root sheath. A line of cleavage can be developed by blunt dissection so that the mandibular and maxillary nerves are exposed in turn and then the ganglion. It is important, as the dura is freed posteriorly from the anterior slope of the petrous ridge, to be on the look-out for the great superficial petrosal nerve. This emerges from a tiny foramen (hiatus Fallopii) in the temporal bone just lateral to the Gasserian ganglion and then passes beneath it (Fig. 62). It must not be avulsed. This can be avoided by leaving the dura attached to the skull at this point. Traction on this nerve, which is a branch of the facial, may cause secondary swelling of the facial, which is then compressed within its tight bony canal. Injury to the great superficial petrosal nerve may result not only in facial palsy, but in injury to the lachrymal fibres which run in the petrosal nerve. The resultant

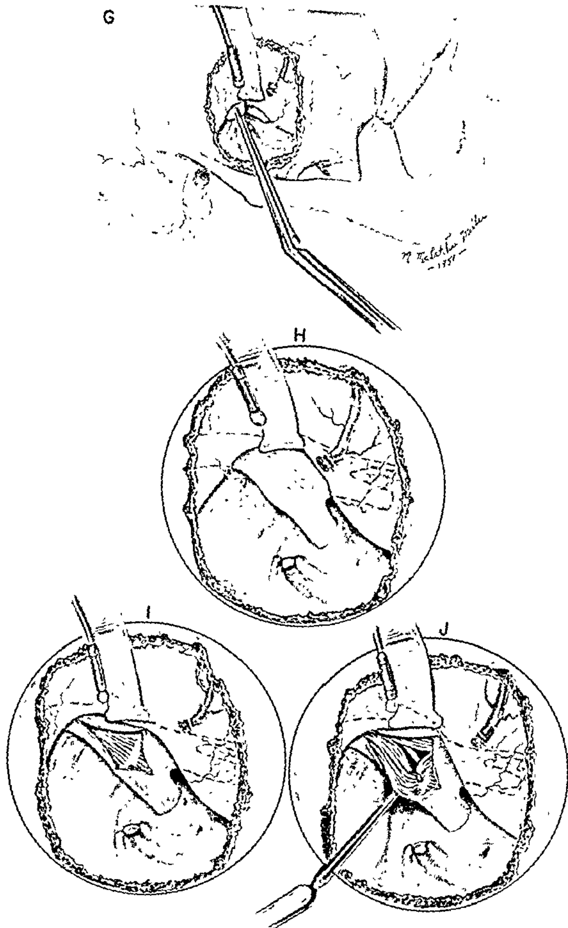


Fig. 54. Retrogasserian neurectomy, subtemporal approach.
G. *Separation of temporal lobe dura from Gasserian ganglion and root sheath.*
H. Exposure of ganglion and its posterior root
I. Opening of root sheath exposing sensory rootlets.
J. Lower two-thirds of sensory rootlets elevated on fine hook prior to sectioning the fibres. Upper rootlets of ophthalmic division and motor root are illustrated above

partial drying of the eye, if it is also rendered anaesthetic by section of the first division fibres, is likely to lead to trophic changes and keratitis, particularly if the lids cannot be closed owing to a peripheral facial weakness.

When the ganglion has been cleared the final step in the exposure is to elevate the temporal lobe dura posteriorly sufficiently to bring the root sheath clearly into view. This is accomplished by thorough separation of the two layers of dura and hooking the curved edge of the lighted Frazier retractor under the posterior edge of temporal dura, so that at least a 1 cm. length of the root is exposed to the point at which it passes over the petrous ridge. The temporal dura then forms an arch over the dura propria of the root sheath, with the ganglion, maxillary and mandibular roots clearly in view (Fig. 54H). The ophthalmic division cannot be seen because it enters the lateral wall of the cavernous sinus, which lies in the upper and most mesial portion of the field.

The root sheath is now opened with a pointed knife in the plane of its fibres and may be split transversely as well (Fig. 54, I). Large amounts of spinal fluid gush out and must be sucked away until the field is dry. It is then possible to see the fine sensory root fibres, sometimes with a small cleft separating the mandibulomaxillary bundle below from the upper and most mesial fibres of the ophthalmic division. The sensory fibres which supply the involved divisions are now picked up on a fine hook and are then best divided with delicate angulated scissors in the shape of an alligator forceps, but with short fine blades at the end. Division with a sharp instrument under direct vision is preferable to the avulsion sometimes recommended, since fine fascicles of arachnoid often connect the rootlets and avulsion may carry away more than the intended number of filaments. It is essential that these rootlets be interrupted well back in Meckel's cave, or otherwise a few ganglion cells may be left centrally which will lead to regeneration and recurrent pain. Every effort must also be made to identify the somewhat larger motor root which runs from above obliquely downward and forward behind the sensory fibres to enter the mandibular division of the nerve. Frazier (1934) claimed that the best way to expose the motor root is to cut the lower lateral fibres of the third division well behind the ganglion. Usually the root can then be brought into view by elevating the more medial second division fascicles, beneath which it runs obliquely downwards to reach the foramen ovale (Fig. 54J). The arrangement of the root fibres is very variable. If numerous or adherent, identification of the intact motor root may be very difficult. It is distinctly larger than the sensory fibres and runs obliquely downwards behind them. When the severed fascicles of the posterior root have been drawn out of Meckel's cave the supposed motor root, if there is any question of its identity, can be tested by stimulation with a microelectrode to see if this results in a contraction

of the masticatory muscles. Whenever the trigger zones of the neuralgia do not involve the forehead and eye, a few of the upper and most mesial fibres should be left intact in order to preserve corneal sensation. On the other hand, in the most severe cases of migrainous headache it is only necessary to sever the upper fibres to desensitize the meninges and cerebral vessels from which the pain arises (Penfield and McNaughton, 1940).

After the appropriate fibres have been thoroughly interrupted posterior to the ganglion, regeneration cannot take place. With a partial section there is always a slight possibility that the neuralgia may spread with later involvement of the remaining portion of the nerve. If this should occur, secondary exposure of the intact fibres within the root sheath is so easy that this possibility need not be a source of concern. If bleeding from venous sinuses is profuse and troublesome, it can be controlled by the application of gelatin foam soaked in thrombin. This should be held in place for several minutes with firm pressure against a cotton pledget marked with a silk thread. When the pledget is removed the foam will usually remain adherent and prevent further bleeding. At the end of every operation haemostasis should be tested by having the anaesthetist compress the jugular veins. When the field remains dry the elevated dura, which with retraction and escape of cerebrospinal fluid has become very lax, is allowed to drop back in place. The incision is closed by approximating muscle, fascia, and skin in layers with fine silk sutures.

Certain difficulties and complications are encountered in connection with this operation: At times the exposure may be difficult because of an extremely adherent dura. In these circumstances it is possible to open it widely by a U-shaped flap and gently elevate the temporal lobe with the lighted retractor protected by cottonoid over a thin rubber strip. Great care must be exercised not to tear bridging veins or contuse the temporal lobe. By feeling with a blunt dissector along the medial portion of the petrous ridge, one can locate the underlying root sheath and open it by incising both layers of dura from above. The desired portion of the retrogasserian sensory fibres can then be cut and the motor root usually spared. Wilkins (1948) prefers this approach, which avoids any risk of tearing the great superficial petrosal nerve and is never followed by facial palsy. Such paralysis, however, is rare even when the root is cut in the middle fossa and the nerve nearly always recovers. Most surgeons feel that the transdural route carries a greater risk of injury to the temporal lobe and therefore prefer to approach the root from below.

Whenever it has been necessary to cut the ophthalmic fibres, or as long as there is any doubt about corneal sensation, it is advisable to cover the eye with a watch-glass taped in position (Buller's shield).

When the patient is returned to bed it is important that the nurse watch

his level of responsiveness over the first few hours. Should recovery from general anaesthesia be unduly prolonged or the patient later lapse into stupor, he should be returned to the operating room without delay, so that the incision can be reopened and a collection of blood evacuated if it is found compressing the temporal lobe. We have seen a fatality at another clinic caused by this complication, and have always since been prepared to adopt this simple precaution.

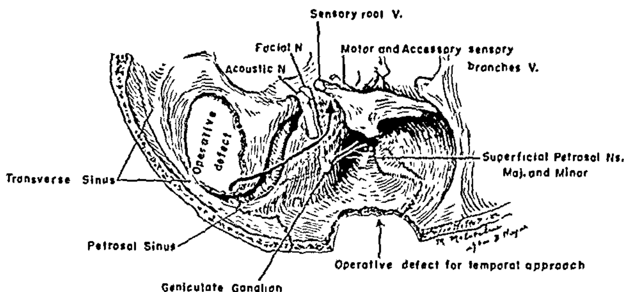


Fig 55. Retrogasserian neurectomy: Dandy's (1929A) figure, redrawn and slightly modified, comparing surgical approaches via middle and posterior fossae.

"When the temporal route is used, facial weakness and paralysis not infrequently follow. Injury to the facial nerve results from trauma to the geniculate ganglion. When the dura, to which the superficial petrosal nerves are frequently attached, is elevated to expose the Gasserian ganglion, the petrosal nerves are torn. At times they are pulled out of the geniculate ganglion. Occasionally, the geniculate ganglion protrudes through a congenital defect in the roof of the petrous temporal bone and is attached to the dura. Direct injury to the geniculate ganglion then causes a more profound facial paralysis."

Figure and quotation from Dandy. *Arch. Surg.*, 1929A. Courtesy, American Medical Association, Chicago.

Retrogasserian neurectomy is not an easy operation for the beginner, but in experienced hands should carry very little risk and give excellent results in properly selected cases. It generally requires from 30 minutes to an hour and a half to perform, depending on the facility with which the dura can be stripped and the amount of venous oozing from deep sinuses.

4. Retrogasserian Neurectomy by the Occipital Approach

Dandy (1929A) was the first to show that the trigeminal root can be exposed and cut where it leaves the pons at the apex of the cerebellopontine angle (Fig. 55). He remained a consistent advocate of this approach be-

cause he occasionally discovered subtentorial lesions compressing the root which he was able to deal with, and because the motor root, which emerges from the brain stem several millimeters further forward, is never injured. There is also less danger of facial palsy. Few other neurosurgeons have been such master technicians in this difficult region, and the general policy in trigeminal neuralgia is to operate by the subtemporal route. The posterior suboccipital approach is nevertheless the preferable one when relief of pain in malignant disease necessitates the simultaneous interruption of other cranial or upper cervical roots; also for relief of the rare case of bilateral tic douloureux when a previous operation has already paralyzed the jaw muscles on one side and the remaining motor root must be safeguarded at all costs*; or when a lesion is suspected of irritating the trigeminal root beneath the tentorium.

This procedure is greatly facilitated if the patient is operated upon in the upright cerebellar headrest (Fig. 66B), which places the incision at the level of the surgeon's eyes and permits spinal fluid and blood to escape by gravity. It is best to use an ether-oxygen mixture administered through an intratracheal tube, which prevents any possibility of the patient's straining and avoids the severe headache which would be experienced under local anaesthesia from air entering the subarachnoid space.

A vertical incision is made in the upper neck to a point just above the inion and then swung laterally and downwards just above the attachment of the nuchal muscles out to the mastoid process (Fig. 56, insert) on the painful side. The upper nuchal muscles are separated in the midline, cut just below their occipital attachment, and scraped off the base of the skull to the foramen magnum. The thin inferior portion of the occipital bone is then perforated by a trephine and rongeured away not quite to the midline and as high and as far laterally as the attachment of the muscles and the mastoid process permit. If any air cells are inadvertently opened they should be plugged with bone wax. Bone is removed nearly down to the foramen magnum, but this need not be opened. The most important part of the craniectomy is to remove the bone and to open the dura as high and as far laterally as the mastoid cells and transverse and sigmoid sinuses will allow, as this is the corner in which the approach to the cerebellopontine angle is made (Fig. 55). Medially, the cisterna magna must be opened and drained.

Once the cistern has been opened widely and the cerebrospinal fluid released, the superior lateral portion of the cerebellar hemisphere is retracted. The route of approach in the angle between tentorium and skull

---

*In this situation we prefer bulbar tractotomy because this operation preserves some corneal sensation and awareness of tactile and position sense of the oral mucosa, tongue, and lower jaw.

to the apex of the cerebellopontine fossa, where the trigeminus leaves the pons and crosses the petrous ridge, is shown in Figure 56, taken from Dandy (1932). Extreme care must be used not to tear any bridging veins between the cerebellar cortex and the inferior surface of the tentorium or sigmoid sinus. These must be coagulated and cut. It is equally important to protect the cerebellar cortex against laceration by placing cottonoid strips and to

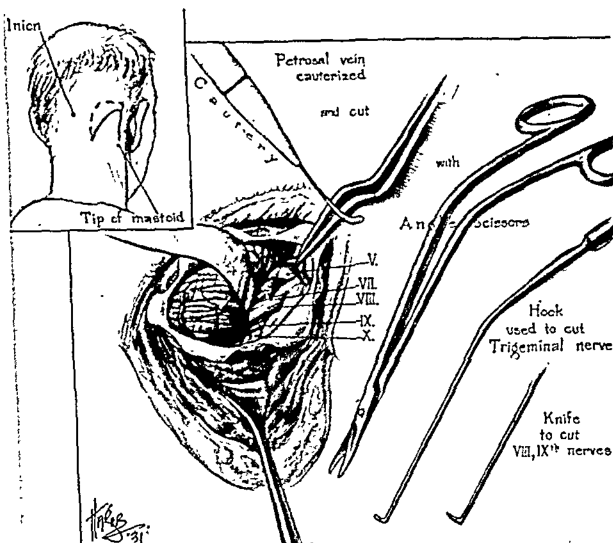


Fig. 56. Retrogasserian neurectomy: Exposure of trigeminal root in cerebellopontine fossa Dandy's (1932) figure. We have found it more convenient to use a slightly larger cutaneous incision, which is indicated in the insert by the dotted line added by us.
From Dandy· Ann. Surg, 1932. Courtesy, J. B Lippincott Co., Philadelphia.

use only the gentlest retraction, merely enough to assist gravity. The seventh and eighth cranial nerves are seen as they enter the internal auditory meatus in the lower part of the field. The delicate arachnoid covering of the lateral cistern should also be opened and drained.

The most crucial part of exposing the fifth root, which lies some 2 cm. rostral to the auditory and facial nerves, is dealing with the petrosal vein,

as this structure may lie directly in the way. Variations in this important vessel are shown in Figure 57, reproduced from Dandy's excellent illustrations. If it cannot be avoided it should be coagulated and cut.

The nerve should now be in clear view over a span of 1 to 1.5 cm. in its course between the pons and the petrous ridge (Fig. 58). It can be freed, elevated on a hook, and severed in whole or in part as desired. Dandy felt that if three-quarters of its root were divided close to the pons, hypalgesia would result throughout the entire face. In contrast to the selective

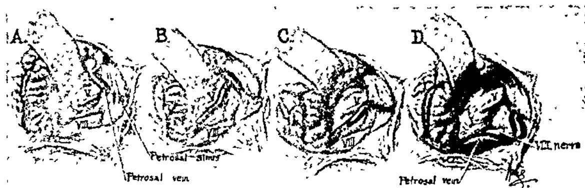


Fig. 57 Retrogasserian neurectomy by posterior approach.

Dandy's (1929A) figure showing variations in the course of the petrosal vein. "The position of this vein is important in making the operation easy or difficult. It is sometimes necessary to divide the vein between silver clips in order safely to expose the sensory root. A, usual course; B, vein bifurcating between the cerebellum and the tentorium; C, vein running posterior to the trigeminus, D, vein running along the base of the skull and over the eighth nerve, practically obscuring it."

Figure and quotation from Dandy. *Arch. Surg.*, 1929A Courtesy American Medical Association, Chicago.

retrogasserian section of the root, the fibres as they enter the pons are completely intermingled, with the result that partial section may somewhat reduce the acuity of sensation throughout the entire trigeminal area to an approximately equal extent (Van Nouhuys, 1932)*. Even if the entire root is deliberately cut, Dandy claimed that partial sensation might remain, due to accessory fibres which leave the pons more rostrally and join the root further down. These are shown in Dandy's illustrations. They may carry only touch and position sense**, and may not supply all the divisions

*Van Nouhuys went so far as to claim that the fibres of the Gasserian root are completely intermingled from the time they leave the ganglion and that Frazier's contention that the root can be cut selectively at this point is "not based on anatomic facts and therefore cannot be regarded as an absolutely reliable procedure." The results of Frazier's selective neurectomy over the past 25 years have proved him right in this matter, although it is evident that the sensory fibres intermingle progressively as the root approaches the pons

**Dandy, who describes these accessory fibres in considerable detail, believed that they come from the main sensory nucleus and do not contribute pain or temperature fibres to the descending tract in the medulla

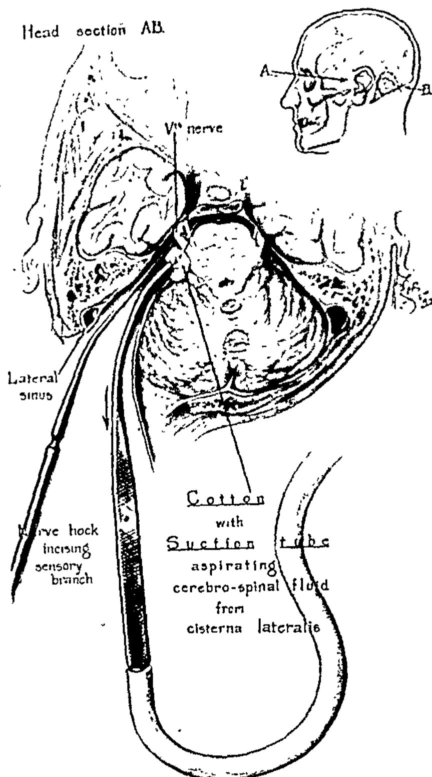


Fig. 58. Retrogasserian neurectomy: Another view of exposure of the trigeminal sensory root in cerebellopontine angle.

Dandy's (1952) figure showing withdrawal of fluid from the cisterna lateralis by suction applied through a pledget of cotton. The drawing shows method of partial division of the sensory root which he recommended in his earlier cases.

From Dandy: *Ann. Surg.*, 1932. Courtesy, J. B. Lippincott Co., Philadelphia.

as this structure may lie directly in the way. Variations in this important vessel are shown in Figure 57, reproduced from Dandy's excellent illustrations. If it cannot be avoided it should be coagulated and cut.

The nerve should now be in clear view over a span of 1 to 1.5 cm. in its course between the pons and the petrous ridge (Fig. 58). It can be freed, elevated on a hook, and severed in whole or in part as desired. Dandy felt that if three-quarters of its root were divided close to the pons, hypalgesia would result throughout the entire face. In contrast to the selective



Fig. 57. Retrogasserian neurectomy by posterior approach.

Dandy's (1929A) figure showing variations in the course of the petrosal vein. "The position of this vein is important in making the operation easy or difficult. It is sometimes necessary to divide the vein between silver clips in order safely to expose the sensory root. A, usual course, B, vein bifurcating between the cerebellum and the tentorium, C, vein running posterior to the trigeminus, D, vein running along the base of the skull and over the eighth nerve, practically obscuring it"

Figure and quotation from Dandy: *Arch. Surg*, 1929A. Courtesy American Medical Association, Chicago.

retrogasserian section of the root, the fibres as they enter the pons are completely intermingled, with the result that partial section may somewhat reduce the acuity of sensation throughout the entire trigeminal area to an approximately equal extent (Van Nouhuys, 1932)*. Even if the entire root is deliberately cut, Dandy claimed that partial sensation might remain, due to accessory fibres which leave the pons more rostrally and join the root further down. These are shown in Dandy's illustrations. They may carry only touch and position sense**, and may not supply all the divisions

*Van Nouhuys went so far as to claim that the fibres of the Gasserian root are completely intermingled from the time they leave the ganglion and that Frazier's contention that the root can be cut selectively at this point is "not based on anatomic facts and therefore cannot be regarded as an absolutely reliable procedure" The results of Frazier's selective neurectomy over the past 25 years have proved him right in this matter, although it is evident that the sensory fibres intermingle progressively as the root approaches the pons.

**Dandy, who describes these accessory fibres in considerable detail, believed that they come from the main sensory nucleus and do not contribute pain or temperature fibres to the descending tract in the medulla.

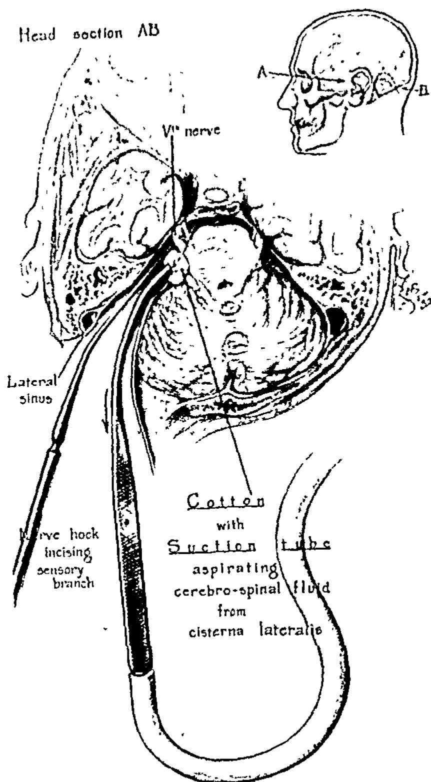


Fig 58. Retrogasserian neurectomy: Another view of exposure of the trigeminal sensory root in cerebellopontine angle.

Dandy's (1952) figure showing withdrawal of fluid from the cisterna lateralis by suction applied through a pledget of cotton. The drawing shows method of partial division of the sensory root which he recommended in his earlier cases.

From Dandy *Ann. Surg*, 1932. Courtesy, J. B Lippincott Co., Philadelphia.

of the nerve. Although we know of no certain means of dividing trigeminal posterior rootlets to obtain analgesia and spare the sense of touch, we have seen occasional patients in whom, following a partial trigeminal rhizotomy, the touch fibres happened to be much more spared than those for pain.

One striking instance of this was Irving R. (MGH U-785310), examined through the courtesy of Dr. Louis Bakay two years after partial left retrogasserian neurectomy. Throughout the left facial skin he localized a 3 gm. hair correctly, but usually failed with a 0.5 gm. hair, which, however, was localized on the normal right facial skin. Over his left forehead only one of 10 jabs with a 40 gm. point felt sharp, six of 10 such vigorous stimuli were sharp on the left cheek, and five of 10 were sharp on the left lower lip.

It is of interest to include recent comments of three of Dr. Dandy's former residents on their observations of partial and complete section of the root at the pons. The following quotations are from letters written in answer to our request for information on this subject:

Dr. Eldridge Campbell stated:

Soon after the suboccipital approach was developed it was his practice to divide the posterior two-thirds or three-fourths (it is difficult to be certain exactly how much one left) for tic douloureux. In patients in whom more than a half of this portion of the nerve had been divided, one was often amazed to find practically no sensory changes, save perhaps for a little hypaesthesia and hypalgesia around the lips, particularly the lower. Since the tic pain was relieved, Dr. Dandy assumed that fibers carrying this pain ran in the posterior portion of the root. In later papers he was careful to make it plain that he referred to tic pain and not pain which the examiner could generate with a pin or by thermal changes Actually, it was his practice, and now is mine, always to divide the entire sensory root when pain of carcinoma was involved. In later years he found that a certain portion of those individuals who had had subtotal divisions suffered recurrence of the tic pain; he once told me this was approximately 10 per cent, which would be in keeping with my experience. For the last five or 10 years of his life, it was, I believe, his practice to divide the entire sensory root for tic douloureux in most instances.

Dr. Barnes Woodhall wrote:

There is no doubt in my mind that he was able to control the pain of tic douloureux with incomplete section and that the residual sensory loss was very small in some cases. It has also been my experience that one must expect recurrences in some of these cases . . . I do not think that one can justifiably delimit the position of the fibres in the root in terms of their entering the medullary tract or the main sensory nucleus.

Dr. Frank J. Otenasek, Dandy's last resident, replied:

> In the later years of his life he did this (partial section) very rarely because of the fact that he noted an incidence of 10 per cent recurrence of the tic pain. It is my feeling that when the entire visible sensory root has been cut any accessory fibres are of no significance . . . I have never seen residual sensation when the entire root has been cut.

5. Medullary Tractotomy of Descending Trigeminal Root

Neurosurgeons are indebted to Olof Sjöqvist (1938A) of Stockholm for his studies on the central course of the trigeminal root fibres. These demonstrated that the poorly myelinated, fine calibre fibres (under 4u in diameter), which transmit pain and temperature sensation, enter the descending bulbar root. This tract runs throughout the entire length of the medulla down to the upper cervical segments (Fig. 59). In verification of his anatomical findings Sjöqvist demonstrated that the root can be readily cut in the posterolateral aspect of the medulla with loss of pain and thermaesthesia, but preservation of tactile and position sensibility.*

Sjöqvist's discovery in man that an incision into the medulla might produce complete trigeminal analgesia came as a surprise to those familiar with the pertinent studies in animals. Gerard (1923) made a series of successively more rostral incisions into the spinal trigeminal tract in cats, each incision about 1.5 mm. above the previous one. She began at the obex and ascended until stimulation of the cornea no longer elicited "pain reflexes" of struggling, pupillary dilatation and rise of blood pressure. Her results from this technique indicated "that the pain fibres from the cornea terminate just below the *upper* 5 to 7 mm. of the tract," i.e., in the midpontine region. Although this conclusion may well be correct for fibres concerned with elicitation of certain feline reflexes, it is clearly wrong for man insofar as conscious pain is concerned. *This represents another instance in which careful animal work in the field of pain has been misleading.* The anatomical study of Winkler (1921, Vol. II, pp. 51-59) was, however, a useful guide. He noted that one group of cells, which he called the *nucleus gelatinosus tractus spinalis*, was the only part of the spinal trigeminal nuclear groups in which the cells resembled those of the *substantia gelatinosa Rolandi* of the spinal cord. The nucleus gelatinosus is found only alongside the lower part of the descending trigeminal tract. The nucleus is well developed at levels below

---

*Unknown to Sjöqvist, Kuntz had made this suggestion in his discussion of a paper by Ranson (1931). The role of the descending trigeminal tract in transmission of pain and temperature had been worked out in animals by earlier investigators (see Chapter XIV), but it is undoubtedly Sjöqvist who developed the practical application of this knowledge to the treatment of human neuralgia

the obex, is much smaller with only scattered clumps of cells between here and the bulbopontine junction at about the site of entry of the auditory nerve, and is not present above this point (see Fig. 59A). The spinal tract of the fifth below the level of the obex also shows the same delay in myelin-

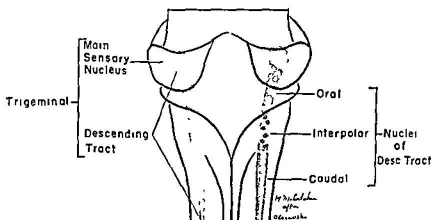


Fig 59A Main sensory nucleus and the descending tract of the trigeminal nerve. The larger myelinated axones carrying touch and position sense enter the main sensory nucleus, the finer myelinated and unmyelinated ones, which transmit pain and thermal sensation, enter the descending tract (Sjoqvist, 1938A) The latter run caudally as far as the uppermost cervical segments Olszewski (1950), who has made a neuroanatomical study of this spinal trigeminal complex, has shown that only the nucleus caudalis has the same fundamental cellular arrangement as is found in the posterior horn of the spinal cord. It is therefore only the caudal part of the descending tract, which lies below the level of the obex, that is concerned with conduction of pain and temperature from the face, he thinks. From our clinical material we place the uppermost terminals of these fibres more rostrally (*see* Chap. XIV), perhaps more in accordance with the earlier description of Winkler (1921), who depicts the upper end of the nucleus gelatinosus of the spinal tract of the Vth about 1 cm rostral to the obex (Fig 59B *on opposite page*)

ation in the 45 cm human foetus that is characteristic of the fasciculus of Lissauer in the cord. Now the substantia gelatinosa Rolandi and tract of Lissauer in the cord appear to be concerned with pain, hence it becomes less surprising that a section of the descending trigeminal tract rostral to the homologous structures, i.e., above the obex as performed by Sjöqvist, would produce trigeminal analgesia.

Olszewski (1950) has made a recent careful study of the morphology of the nuclei of this tract in both man and monkey (Fig. 59A). He finds that the "subnucleus gelatinosus," homologous to the cord's substantia gelatinosa Rolandi, extends up only as far as a cross-sectional level 1 to 2 mm. below the obex, along with two other subnuclei to make up what he calls the caudal nucleus of the spinal trigeminal tract (Fig. 58A). From here on up to the rostral third of the inferior olive he finds cells of different type and calls this zone the interpolar portion of the nucleus. He therefore con-

cludes that only the caudal portion of the nucleus is concerned with the sensations of pain and temperature, but cannot explain certain reports that an incision as far as 6 or 8 mm. below the obex can produce complete trigeminal analgesia (see p. 462).

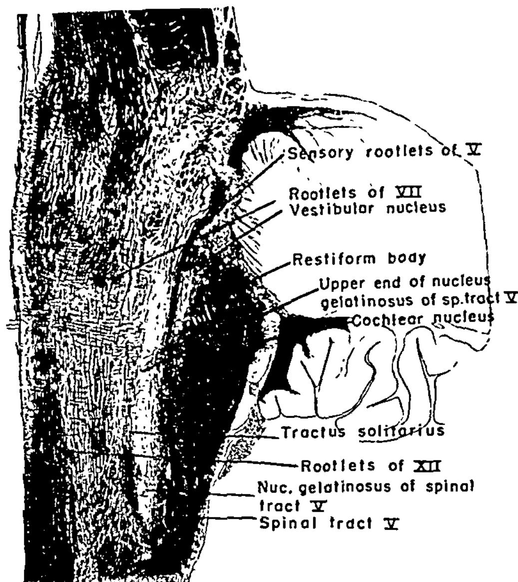


Fig. 59B. From Winkler, 1921 Courtesy de Erven F. Bohn, Haarlem.

According to our findings, a wide incision at this lower level usually produces at most analgesia limited to the skin of the trigeminal area. To ensure with reasonable certainty analgesia of the trigeminal mucosa as well, we find that the incision must be close to the obex; hence we place the cells concerned with trigeminal innervation of the mucosa more rostrally than those for the skin. Our clinical results differ from Olszewski's interpretation only to the extent that we place a small portion of the pain nucleus rostral to the obex.

Full details concerning the development and a clinical evaluation of this operation are given in Chapter XIV. It has certain disadvantages, as well as outstanding advantages over the standard retrogasserian neurectomy. Among the former may be listed a somewhat greater mortality rate and, in particular, the difficulties of attaining and maintaining full, lasting analgesia. On the favourable side, it has been pointed out by Sweet (1948) that sufficient corneal sensibility is preserved to eliminate the risk of paralytic keratitis. Also of considerable advantage is the additional independent finding of Brodal (1947A) and Sweet that pain fibres from the nervus intermedius, glossopharyngeal, and vagus are also interrupted. Hamby *et al.* (1948), who have corroborated this important observation, report that, after examining three patients postoperatively, they found "analgesia of the entire ipsilateral half of the tongue, palate, uvula, and tonsil and its pillars, and of the accessible portion of the pharynx. All three had analgesia of the entire auricle and external meatus, and of an area behind the ear extending down on the mastoid process." For further discussion of this and other clinical features of interest, see Chapter XIV. It is here important to note only certain facts that are essential to guide the technical steps of the surgeon.

When the operation was first performed in man by Sjöqvist and by Grant, Groff, and Lewy (1940), the section was made above the level of the obex just dorsal to the plane of the lowest vagal rootlet (Fig. 60A). When the medulla was incised at this rostral level, patients were frequently troubled by postoperative ataxia of variable severity and duration. It soon became apparent that this disagreeable complication was caused by injury to the caudal portion of the restiform body. Grant and Weinberger (1941A) therefore suggested making a transverse incision in the same plane but some 4 mm. caudal to the obex (Fig. 60B). From Olivecrona's (1942) report it is evident that the Swedish surgeons have adopted this level of transection, which is 10 to 12 mm. below the point originally advocated by Sjöqvist. When carried out at this point, interruption of the pain fibres may be nearly as complete and there is no danger of producing cerebellar ataxia. Similar considerations apply when the spinothalamic tract is to be cut in the medulla (p. 221).

McKinley and Magoun (1942A), who have examined the relative position of facial pain fibres in the descending root by action potentials, found that, although there is great overlapping, the axones from the three trigeminal divisions tend to be laminated in a dorsoventral order, so that those from the ophthalmic division lie most ventral and descend to the upper cervical segments of the cord, while the mandibular afferents are situated most dorsally and many stop at the level of the obex. This is in accord with our own and the majority of published observations after operation, but not with all, as is described in more complete detail in Chapter XIV.

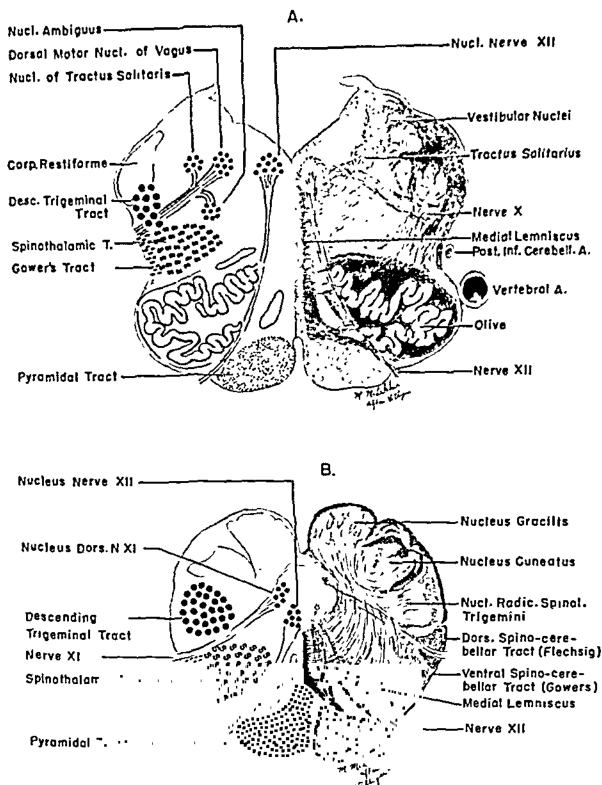


Fig 60. Position of descending trigeminal and spinothalamic tracts in upper (A) and middle (B) portions of medulla.

We place the heavy stippling for the descending trigeminal tract in B so as to overlie the nucleus of that tract as well. We mean thereby to suggest that the surgeon should cut to this depth, because the medial zone of the nucleus consists mainly of relatively fine myelinated fibres which run longitudinally, and which may well be important pathways for pain.

Medullary tractotomy is therefore most useful in treating first division neuralgia, especially in individuals who work in dusty trades or whenever total loss of corneal sensation is of special concern. It is also of particular value in cases of bilateral trigeminal neuralgia, if the motor root has been paralyzed on the one side by a previous subtemporal operation; when carcinoma of the antrum has spread to involve the area of the temporal approach; or when multiple cranial nerves are involved which require a suboccipital exposure. In these cases it is a substitute for higher division of the nerve where it leaves the pons. After the descending medullary tract has been widely cut, analgesia also develops in the distribution of the nervus intermedius, the glossopharyngeal, and the cephalic branches of the vagus.

Testing of the patient following incision of the bulb is, we think, particularly important. Consequently it is necessary to operate under local anaesthesia, but this must usually be supplemented with some short-acting general anaesthetic, such as light Pentothal with inhalation of nitrous oxide or Trilene, as the incision is made in the bulb. This is usually too painful to be tolerated by the patient. It is advisable to use the lateral cerebellar position to avoid pain from the incidental entrance of air into the cerebral subarachnoid space which occurs if the patient is operated upon in the sitting position.

Trigeminal tractotomy has fallen into disuse in some quarters because of the difficulty in securing a lasting analgesia over the desired areas, but with either the method we have used or that of Falconer (1949) this difficulty seems avoidable. After a removal of the occipital bone for 2 to 3 cm. above the foramen magnum, with added resection of the posterior arch of the atlas if necessary, the dura mater is opened with a T-shaped incision, its long arm placed somewhat parasagittally on the side of the pain. We have not been able to identify at operation the bulge of the inferior olive, the tuberculum cinereum corresponding to the descending trigeminal tract, nor its separation from the region of the nucleus fasciculus cuneatus. The only pertinent landmarks we have been able to find with certainty are the obex (lower tip of the fourth ventricle) and the line of emergence laterally of the spinal accessory rootlets. It is well to see two of these widely separated rootlets—one above and one below the point of incision—in order that their line of emergence may be established. This is somewhat diagonal, not horizontal, and moves ventrally as one proceeds rostrally. An incision placed several millimeters rostral to but in the plane of emergence of a lower rootlet is likely to enter the bulb too far dorsally to cut all of the descending pain fibres. We have tried to avoid the disappointments of inadequate analgesia from too caudal an incision, on the one hand, and, on the other, of lasting ataxia from too rostral an incision which will involve the restiform body. This can be achieved only by making an adequate ventrodorsal in-

cision in the cross-sectional plane at or just below the obex. The restiform body lies rostral to this, and nearly all of the primary afferent neurones coming up from below and entering the nucleus cuneatus have done so lower down. One may therefore make a generous incision at this level with *impunity*. We have learned from spinothalamic tractotomy that no significant disability follows incision into the bulb immediately ventral to the descending trigeminal tract. Consequently one may incise ventrally with relative impunity to make certain of dividing and not merely contusing all

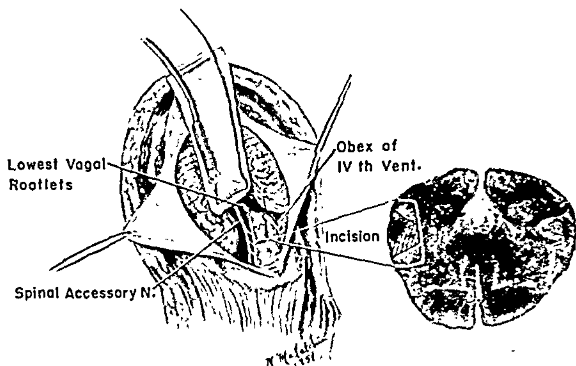


Fig. 61. Medullary section of descending trigeminal root.

Insert from Grant and Weinberger (1941B), reversed, shows incision below obex recommended by them (oblique black lines) and somewhat more extensive incision preferred by us (shown by white line).

We prefer, when the vascular pattern in the pia permits, to make the cut at the cross-sectional level of the obex rather than below it as shown in the illustration

of the ipsilateral cephalic pain fibres. In order to accomplish this the incision should be started ventral to the line of emergence of the spinal accessory rootlets and carried dorsally well into the nucleus cuneatus.

The incision is made to a depth of 3.5 to 4 mm. We have found it most convenient to use a broken-off pointed knife blade (a No. 11 Bard-Parker) projecting the correct distance from the jaws of a haemostat. The extent and anatomical relationship of the incision are illustrated in Figure 61. The actual cutting of the descending trigeminal tract is more painful than that of the spinothalamic tract, and the patient should receive Pentothal or

some other short-acting intravenous anaesthetic agent just prior to this As soon as the patient awakens an assistant should examine for analgesia not only throughout the ipsilateral face and tongue but also in the contralateral leg. If that leg does not show reduced pain sensation the incision should be extended slightly in a ventral direction. The only significant undesirable sequel of such an incision may be a transitory ataxia of the ipsilateral upper limb with ipsilateral lateropulsion. We have secured lasting analgesia and relief of pain in trigeminal neuralgia only by such an incision at the level of the obex. When we have made less generous ventrodorsal incisions (presumably confined to the descending cephalic pain fibres) or have incised 5 to 8 mm. caudal to the obex, the analgesia has tended to be inadequate to prevent a later recurrence of trigeminal pain. Falconer (1949) also has succeeded in placing his incisions so as to give lasting relief of trigeminal neuralgia in all 14 of his reported cases. In his later operations he mapped out the extent of the descending tract in the conscious patient by pricking the medulla to a depth of 3 mm. with a straight surgical needle. Entrance into the descending tract causes "slight momentary pain in the appropriate part of the face." This simple manoeuvre may make incisions as extensive as ours unnecessary, although Falconer's patients with incisions aided by this tactic have not been followed long enough to be certain that recurrence has been obviated.

According to Walker (1939) the topical arrangement of fibres within the descending trigeminal tract has been fairly well agreed upon by all investigators. Bregman (1892) found that degeneration was present in the ventral portion of the spinal tract in animals with an absent corneal reflex or keratitis, and in only the dorsal portion of the tract when first division sensation was preserved. Spiller and Frazier (1901), Wallenberg (1904), and Kutner and Kramer (1907) all came independently to the same conclusion.

We have never observed any significant neurological sequel from injury to the dorsally adjacent nucleus cuneatus. Transitory complications which have been encountered have consisted of: headache due to blood and air entering the subarachnoid space; hiccough, mentioned by Grant; herpes labialis; and recurrent laryngeal palsy reported by Sjoqvist, but not seen by Grant or by us. Olivecrona (1942) has pointed out that this complication is avoided by using the lower incision, which is not so close to the caudal motor rootlets of the vagus.

The advantages of medullary tractotomy are that the face and eye do not become anaesthetic. Walker (1939) and also Grant and Weinberger (1941B) have found that the sensation of touch to graded von Frey hairs is only slightly reduced and awareness of position of the tongue and food in the mouth is not lost. This protects the patient from biting his tongue or

lips (an important consideration when a bilateral operation is necessary—see Rowbotham, 1939) and eliminates the sense of numbness, which may be so disagreeable to neurotic individuals. Furthermore, preservation of some degree of corneal sensation has proved to be a protection against trophic keratitis, although a single complication of this sort has been reported (see Guidetti, p. 455). One of us (Sweet, 1945) has shown that loss of pain may also include the cephalic distribution of the sensory portion of the seventh (nervus intermedius) and ninth and tenth cranial nerves. On the other hand, transection of the descending root in the medulla is no more effective than retrogasserian division of the root in the middle fossa or at the apex of the cerebellopontine angle for atypical facial or postherpetic neuralgia. The risk of mortality is somewhat higher than with these procedures and, most handicapping of all, recurrences from gradual replacement of analgesia by hypalgesia are relatively frequent (Grant and Weinberger, 1941B; Olivecrona, 1942; and Hamby *et al.*, 1948). The latter have reported a mortality rate of 46 per cent in 13 operations for pain due to neoplasm and 5.7 per cent in 35 operations for trigeminal neuralgia. We have rarely utilized this procedure for the relief of tic douloureux and are only willing to recommend it under special circumstances when the neuralgic pain starts in the ophthalmic area, is bilateral, or when the patient wishes at all costs to avoid total numbness of the face.

C. SECTION OF THE GREATER SUPERFICIAL PETROSAL NERVE

The greater superficial petrosal nerve leaves the facial at the geniculate ganglion to enter the middle fossa through the hiatus Fallopii. It carries parasympathetic secretory fibres to the lachrymal gland and nose, and is joined by the deep petrosal which carries sympathetic vasomotor fibres from the carotid plexus. The combined vidian nerve then runs to the sphenopalatine ganglion. There is also evidence that fibres transmitting pain and taste run in the greater superficial petrosal nerve. We have stimulated the central end of the divided nerve electrically at operation under local anaesthesia and evoked pain in the majority of cases referred to the ipsilateral face and ear. This persisted after trigeminal root section in several instances where this could be tested. Schwartz and Weddell (1938) have shown that taste from the anterior two-thirds of the tongue is occasionally lost on one side when the nerve is cut deliberately or torn in retrogasserian neurectomy. Since Gardner *et al.* (1947) have described a great superficial petrosal neuralgia, it is at times desirable to perform a neurectomy.

The surgical exposure, which is easily done under local anaesthesia, is carried out in identical fashion to the exposure of the mandibular root in

the standard Frazier operation via the temporal approach. After the middle *meningeal artery has been coagulated and cut, the dura is elevated off the* medial anterior portion of the petrous bone. As this is stripped posteriorly the nerve comes into view as it emerges from the hiatus Fallopii and runs obliquely forward beneath the origin of the mandibular nerve from the ganglion (Fig. 62). It can then be stimulated to see if this causes the pain complained of. Spread of current to the facial nerve also causes the facial

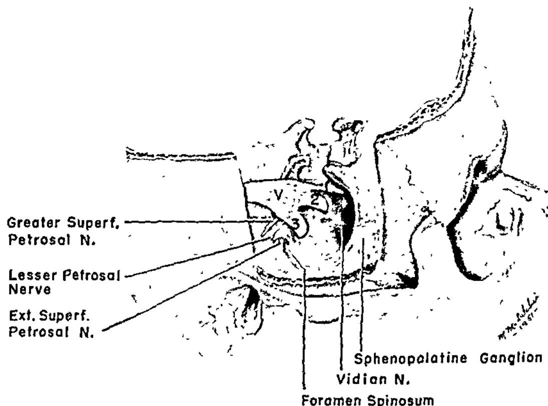


Fig. 62. Anatomical relationships of the three divisions of the petrosal nerve as they emerge from the petrous portion of the temporal bone in the middle fossa.
Although the vidian nerve and sphenopalatine ganglion cannot be seen from the middle cranial fossa, their course deep to the floor of the fossa is indicated in outline.

muscles to twitch when the electrode is applied to the central end, while stimulation of the distal end should induce tearing and reddening of the conjunctiva. The nerve should be cut without traction as it leaves the bone, because this may be followed by facial palsy. It is best to excise the greatest length possible in order to prevent regeneration. Our experience with this operation is summarized in Chapter XVI.

D. SECTION OF NERVUS INTERMEDIUS

The fact that pain deep in the ear* without radiation to the throat may be transmitted by the nervus intermedius, the tiny sensory division of the facial, was clearly shown by Furlow (1942), who evoked such pain by stimulation of the nerve and relieved his patient of a severe intermittent neuralgia by its selective avulsion. Pain deep in the ear, in either cancer or other conditions, has often been an insoluble problem. This is discussed in Chapter XV, where we cite two further successful cases in which we have interrupted the nerve.

The approach to the nerve is similar to the standard exposure of the eighth which has been described by McKenzie (1936) for vestibular neurectomy in Menière's disease. The operation will be made much easier for the surgeon if the upright cerebellar headrest is used. With this it is best to use general anaesthesia. When it is desirable to stimulate before cutting the root, light Pentothal and nitrous oxide or Trilene may be used as a supplement to local. The lateral cerebellar position shown in Figure 66C is then preferable so that the cerebrospinal fluid in the cerebral cisterns, sulci, and ventricles will not be painfully replaced by air. The same unilateral suboccipital craniectomy is used as in division of the trigeminus at the pons. After opening the dura and draining the cisterna magna the cerebellar hemisphere is gently retracted towards the midline and the lighted retractor inserted to expose the lateral wall of the posterior fossa. The internal auditory meatus is easily brought into view. At first only the auditory nerve is seen with its vestibular portion somewhat above and further forward. If both portions of the eighth are gently depressed or elevated on a hook, the facial will be seen just rostral. The fine filament of the nervus intermedius lies on its posterior surface, as is illustrated in Figure 63, and can be cut after it is lifted away from the facial. On rare occasions the vestibular portion of the auditory nerve contains at least a part of the course of the nervus intermedius. If it cannot be found, the search may be facilitated by cutting this rostral division of the eighth nerve which provokes no clinical deficit. The nervus intermedius may then be seen passing distally into the vestibular portion of the eighth nerve. Bischoff (1865) has described this and we have seen it once in the course of a series of dissections in cadavers.

E. GLOSSOPHARYNGEAL NEURECTOMY

The ninth cranial nerve carries taste fibres from the posterior third of the tongue, as well as sensation from this area and from the posterior portion

*For a description of the sensory innervation of the outer and inner ear see Chapter XV.

of the soft palate, fauces, Eustachian tube, and pharynx as far down as the epiglottis (Fig. 64) (Dandy, 1927; Stookey, 1928*A;* Hoover and Poppen, 1936; and Erickson, 1936). While the former were unable to detect any *change in sensation of the external ear, Erickson found that the drum in* his patient lost its sensation.* A few somatic motor fibres supply the stylo-

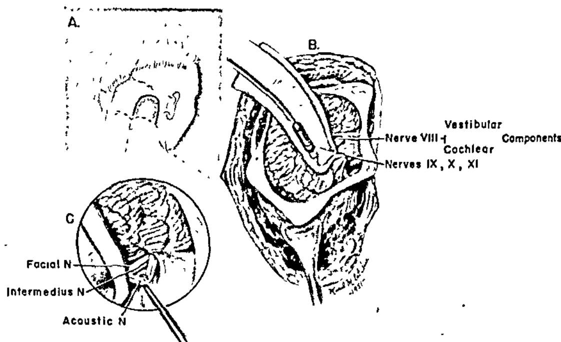


Fig 63 Exposure of nervus intermedius.

pharyngeus muscle. Dandy, Erickson, and Hoover and Poppen, as well as we, have been unable to detect any paralysis after the nerve has been cut. The slight residual palsy of the soft palate noted by Stookey as well as by Reichert (1931, 1933 *A* and *B*, 1934) was perhaps due to transitory involvement of contiguous vagal fibres. Indeed, Reichert (1933A) stated that in his patient "the nerve was not readily identified because it was adjacent to and touched the upper fibers of the tenth at the pons and coursed behind these fibers as it neared its foramen." Parasympathetic motor fibres also run in the glossopharyngeal and innervate the parotid gland. Reichert and Poth (1933A) from their quantitative measurements of salivary secretion claimed that the submaxillary and lingual glands are also temporarily affected, but Erickson found only the parotid involved.

Dandy (1927) showed that intracranial division of the nerve as it leaves the medulla is a simple and safe procedure, and this route has since been

*This is not often the case as, according to Gray's anatomy (1942), in addition to its nerve supply from the tympanic branch of the glossopharyngeal, the tympanic membrane is innervated by the auriculotemporal branch of the mandibular and from the auricular branch of the vagus.

used in preference to the earlier extracranial section. Selective section of this nerve is used in typical glossopharyngeal neuralgia and in the rarer form of neuralgia involving Jacobsen's tympanic plexus. Section of the ninth in conjunction with the fifth, sensory portion of the seventh, upper vagal fibres, and posterior cervical roots is also employed to alleviate the pain of

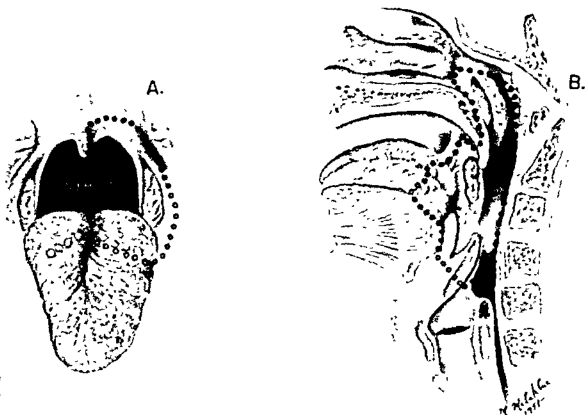


Fig. 64. Sensory distribution of glossopharyngeal nerve.

This diagram is compiled from Dandy's (1927) first two cases (examined by Crowe) and is substantially the same as that illustrated by Hoover and Poppen (1936). In none of our own cases has the analgesia been so extensive (page 482). Our examinations have shown that anaesthesia of the soft palate and uvula may be absent or very slight. It is also pertinent to add that the area of sensory loss in the nasopharynx and larynx is extremely difficult to map accurately. This is because of individual variations of sensibility in normal subjects and the activity of the gag reflex in the non-cocainized pharynx, which Dr. Charles I. Johnson has graphically demonstrated by attempts at nasopharyngeal and laryngoscopic examination on ourselves.

carcinomas which invade the ear, tonsil, and oropharynx. Occasionally these patients are in such a poor state of nutrition from pain and inability to swallow that protein and electrolyte balance must be restored before operation can be undertaken. In the case of classical glossopharyngeal neuralgia, spraying the painful "trigger" areas in the throat with cocaine will give relief for several hours so that the patient can eat several large meals in comfort.

As in all posterior fossa rhizotomies, the glossopharyngeal nerve is exposed most easily with the patient in the upright cerebellar headrest, although the lateral position illustrated in Figure 66C is quite satisfactory and safer. For reasons given above we prefer general anaesthesia, or local supplemented by light Pentothal and nitrous oxide, if the sensory distribution of the nerve is to be tested.

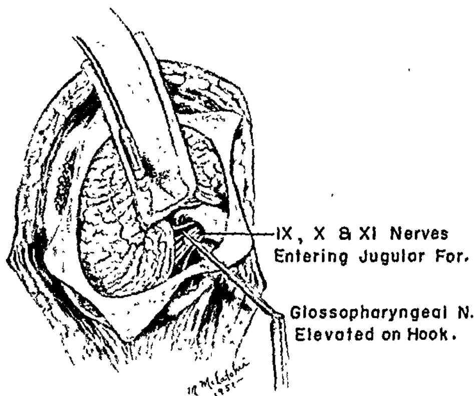


Fig. 65. Glossopharyngeal neurectomy.

The glossopharyngeal nerve is shown as a single root, somewhat larger than the individual vagal rootlets. This is the way it appears to the surgeon. Actually, when examined with a magnifying lens in a postmortem specimen, one can see that what looks like a single root can be separated into a number of tiny rootlets

A satisfactory exposure is obtained by making a midline cervical incision and curving it laterally along the occipital ridge to the base of the mastoid process. Only a small unilateral suboccipital craniectomy is required, leaving the rim of the foramen magnum intact. When the dura has been opened and the cistern drained, the nerve is exposed by drawing the cerebellar tonsil and the lateral portion of the hemisphere upward and toward the midline (Fig. 65). The combined glossopharyngeal and vagal rootlets are readily identifiable as they course obliquely forward and laterally to enter the jugular foramen with the rostrally directed fibres of the spinal accessory nerve. We

have found no difficulty in separating the well defined single rootlet of the ninth from the larger, more caudal bundle of the vagal complex; in fact, the glossopharyngeal leaves the jugular foramen through a separate opening in the dura. It is elevated on a fine hook and cut. One or two of the most rostral rootlets of the tenth, which Tarlov (1940) has shown are purely sensory, can also be cut in cases of carcinoma with pain in the pharynx and ear. Under these circumstances (see p. 504) we believe it is also advisable to divide the nervus intermedius, which is easily reached in this exposure. In most cases of "glossopharyngeal" neuralgia it is also advisable to divide the uppermost vagal rootlets (see Chap. XV).

CHAPTER VIII

INTERRUPTION OF PAIN PATHWAYS IN SPINAL CORD, MEDULLA, AND MESENCEPHALON

THE SPINOTHALAMIC TRACT is accessible to the surgeon throughout its spinal portion and in certain parts of the medulla and the mesencephalon (Fig. 12). Transection of the spinal pain pathway, on the basis of Spiller's observation in 1905, was first carried out by Martin at Spiller's suggestion 40 years ago (1912). Schüller (1910) appears to have been the first to propose that the anterolateral column of the cord be deliberately divided for relief of pain; he advanced this notion as a treatment for the gastric crises of tabes. Among those who have contributed the most in developing the operative technique and in establishing the value and limitations of this procedure are Banzet (1927), the Russian Babtchine (1929), Foerster and Gagel (1932); Grant (1930), Hyndman and his collaborators (1939, 1943), and Kahn and Peet (1948) in this country; and Sjöqvist in Sweden (1949). Following Leriche's suggestion the French have been cutting the central commissure of the spinal cord to interrupt the pain fibres in the region of their decussation,* and more recently Schwartz and O'Leary (1941), White (1941) and Walker (1942A) have shown the feasibility of transecting the spinothalamic tracts in the medulla and mesencephalon.

A. ANTEROLATERAL CORDOTOMY

We have insisted on the necessity of establishing the level and completeness of sensory loss at the time of operation.** Time and again what has appeared to be a radical transection of the anterolateral column has been found to abolish appreciation of pain no higher than the lowest thoracic dermatomes. It usually takes a second or even a third deeper incision to raise the sensory level to the xyphoid. At times, furthermore, islands of incomplete loss of appreciation of pain within the zone of otherwise complete analgesia will be missed unless they are searched for prior to closing the incision. The following is an example of this:

*This possibility was also explored at the Massachusetts General Hospital by Putnam (1934), but as he did not sever the decussating pain-conducting fibres completely the resulting analgesia was of brief duration.

**This means total unawareness of pain on rapid repetitive pricking of the skin with a sharp pin, or pinching with the points of a towel clip.

Harry C., MGH U-756313, had been submitted to right and left-sided cordotomies at the level of the second and third thoracic vertebrae in March and July, 1952, for pain from recurrent rectal carcinoma. He then had complete relief in the left pelvis and lower extremity, but an early recurrence in the right buttock and perineum. Sensory examination revealed a good level of analgesia to T7 on both sides, but on the right islands where repetitive pricking with a pin or even a single forceful impression caused discomfort in the buttock and down the medial side of the leg to the internal malleolus. Therefore the left side of his cord was again exposed under nitrous oxide-Pentothal and local anaesthesia on 11/3/52. The resident then made a 5 mm. deep transverse incision just in front of the dentate, and with the Frazier cordotomy hook transected a large part of the left anterolateral quadrant to a point just anterior to the motor root. The patient was awakened and pain sensibility was tested by one of us. While analgesia had been extended upwards well up over the ribs, it was found that islands of sensibility to pain in the buttock were still present. The incision in the cord was re-examined. As there was no doubt that it extended nearly to the midline of the cord just in front of the dentate plane (the area in which the lumbosacral fibres should lie), a second cut was made to divide the remaining ventromedial fibres between the motor root and the anterior spinal artery. On retesting analgesia had become complete and so remained to the nipple line up to the time of his discharge.

It is therefore of vital importance to perform the operation under local anaesthesia, a point emphasized long ago by Foerster (1927B) and Grant (1930), among others. Kahn and Rand (1952) have recently recorded a number of failures to relieve pain in this area when the operation was performed under a general anaesthetic. Apprehensive individuals may have the primary infiltration of procaine supplemented by a light dose of intravenous sodium Pentothal with inhalation of nitrous oxide or Trilene plus oxygen, so that they may be kept asleep until the cord or brain stem has been exposed and incised. It is a striking fact that the actual incision into the spinothalamic tract with the patient awake rarely causes severe pain. Usually there is virtually no pain–an extraordinary finding to which many have attested–Wilson and Fay (1929), Grant (1930), Foerster and Gagel (1932), Sasaki (1938), Sjöqvist (1949), to name a few. Slight tension on a posterior root, however, must be avoided at the time of incision of the cord, since it may cause intolerable pain in the territory of that root. If the patient is asleep at this time, it is essential that he be given time to regain an adequate level of consciousness. If recovery is unduly prolonged, it may be accelerated by the intravenous use of Metrazol (100 mg.), Benzedrine sulphate (10 mg.), or Picrotoxin (1 to 10 mg.), but usually only a little patience is necessary. The patient should always be coached preoperatively on the method of testing and the vital importance of his cooperating and differentiating be-

tween the sharp point of a needle, or the nip of a towel clip, and the dull sensation of touch, which he will still feel in the analgesic zone.

The strength in the limbs ipsilateral to the incision is also tested after each added cut. If any definite weakness appears no further incision should be made; the weakness then usually becomes inconsequential within a few days.

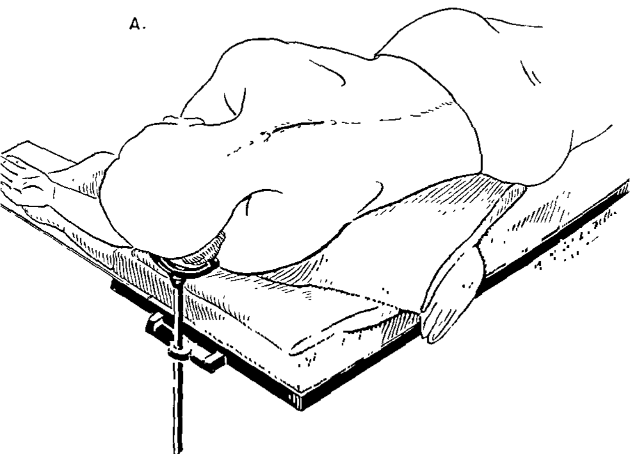


Fig. 66. Placement of patient on operating table for various operations on cranial nerves or pain pathways in brain stem and upper cord.
A. Semilateral position for upper thoracic cordotomy.

Few of our patients have been unable to tolerate this operation under local or remained too groggy to cooperate on awakening from the combined Pentothal-nitrous oxide or Trilene narcosis. The proportion of failures in this group amounted to 27 per cent in contrast to 11 per cent of those in whom accurate verification of a satisfactory level was demonstrated on the table. During the last five years, when we have routinely supplemented procaine infiltration in this way and our anaesthetists have become more proficient, failures to secure satisfactory sensory testing and adequate levels of analgesia have steadily decreased.

Our method of transecting the pain pathway in the upper thoracic cord

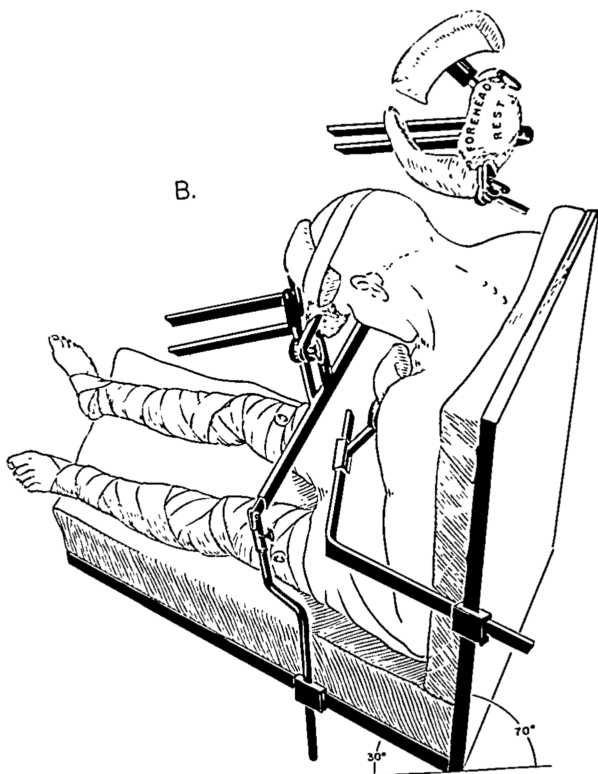


Fig 66B Sitting position in Craig headrest.

is substantially that described by Grant (1930) and Kahn and Peet (1948). Unless a bilateral cordotomy is to be done, we prefer to place the patient in the semilateral (45 degree) position, as illustrated in Figure 66A. This is always preferable to the prone position, in which respiratory exchange is somewhat restricted and the return of blood to the right side of the heart impaired. With the patient prone falls in blood pressure are common,

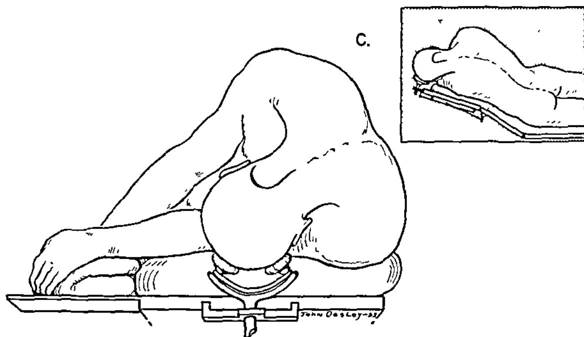


Fig 66C. Lateral cerebellar position.

While the sitting position gives the surgeon the best possible exposure for all operations on the upper cord, medulla, and cranial nerves in the cerebellopontine angle, the patient, if awakened for testing, may be distracted by headache from air having entered the ventricles and subarachnoid space. There is also the potential risk of aspiration from an opened vein and collapse from air embolism. Five fatalities from this complication have been reported by Hamby and Terry (1952); one patient was revived by quickly shifting to the prone left lateral position. The rationale of this manoeuvre is based on the observation of Durant *et al.* (1947) that, when an experimental animal is placed in this position, blood can be seen to pass the air trap in the right auricle.

especially in heavy, elderly individuals. Our anaesthetists therefore prefer the lateral position, and it also gives them better access to the patient's nose and mouth for supplementary inhalation of anaesthetic gases than when the patient is lying prone. From the viewpoint of the surgeon, who stands facing the patient's back, the lateral oblique position gives an excellent exposure of the anterolateral quadrant after the cord has been rotated.

For relief of pain below the xyphoid level, the incision is made over the spines of the upper three thoracic vertebrae. It is necessary to remove only a single entire lamina, plus the lower half of the one above and the upper half of the one below. On opening the dura, the large bundle of

rootlets at the first thoracic level stands out as it enters the dura at the upper end of this exposure. It is best to incise the cord at its second thoracic segment. The dural attachments of the dentate ligament are cut on each side, as recommended by Kahn and Peet, to permit maximal rotation of the cord. Often it is necessary to cut two fasciculi on the side of the incision. The dentate ligament is then grasped with a fine snap close to its attachment to the cord (Figure 67A). It is of vital importance that care be taken in this step because, if the dentate be grasped a millimeter or two from its insertion, the tip of the haemostat will not mark the boundary between the spinothalamic and corticospinal tracts, but will point somewhat dorsal to it over the motor pathway. If the dentate ligament is either torn or has developmental gaps at its origin from the cord, one may follow Frazier's (1920) original tactic of selecting the point halfway between the emergence of anterior and posterior roots as the dorsal limit of the incision. This procedure has also been recommended by Stebbing (1929) and Babtchine (1929). A single posterior root may be cut if it will facilitate the exposure, but this is often unnecessary. Our preference now is to leave the posterior roots intact, since their division does not seem to reduce the incidence of radicular pain. Brief application to the rootlets of a cotton pledget soaked in 2 per cent procaine will eliminate pain when they must be cut.

These preliminaries completed, the cord may be rotated nearly 90 degrees or, alternatively, in order to avoid rotational distortion, one may gain additional space by removing most of the pedicle just lateral to the proposed site of incision into the cord. We use the broken-off triangular pointed tip of a No. 11 Bard-Parker knife blade, which projects 5 mm. from the jaws of a small haemostat, to make the primary incision in the cord in the usual upper thoracic cordotomy in adult patients (where the average transverse diameter of the cord averages 12 mm. ± 1). At higher levels, C2 and C5, where the respective diameters of the cord average 12.5 and 15.0 ± 1 mm. respectively, the blade should project to a correspondingly greater extent. This is used to sever the pia mater and to make the primary incision on a transverse plane just anterior to the attachment of the dentate ligament (Fig. 67B). The curved cordotomy hook* is then inserted into the incision and swept ventromedially until its tip emerges at least 2 mm. medial to the zone of origin of the anterior spinal rootlets.

In order to secure a maximally high level of analgesia we deliberately attempt to transect virtually the entire anterior quadrant of the cord, with due precautions not to injure the anterior spinal artery (Fig. 68), a tactic

*The Frazier cordotomy hook we have used is a fine half-round hook, 4 mm. in diameter, fixed at right angles on the end of a delicate handle. By this means the fibres to be cut are elevated and then severed on the hook by a fine sharp knife.

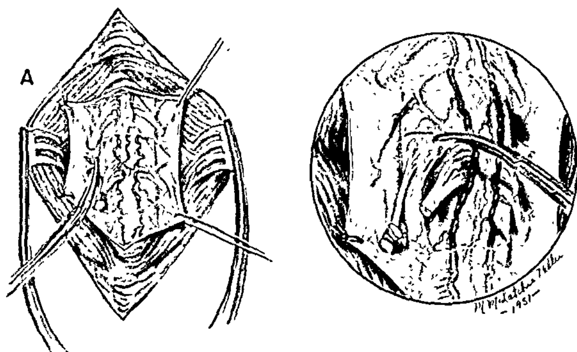


Fig 67. Anterolateral cordotomy at upper thoracic level.
A. Details of exposure and rotation of spinal cord
B Technique of rotating spinal cord by section and traction on dentate ligament and transection of anterolateral quadrant.

B.

Denticulate Ligament

Post. Root

4 to 5mm

No. II Knife Blade

Ant Root

Ant Spinal Artery

Frazier Cordotomy Hook

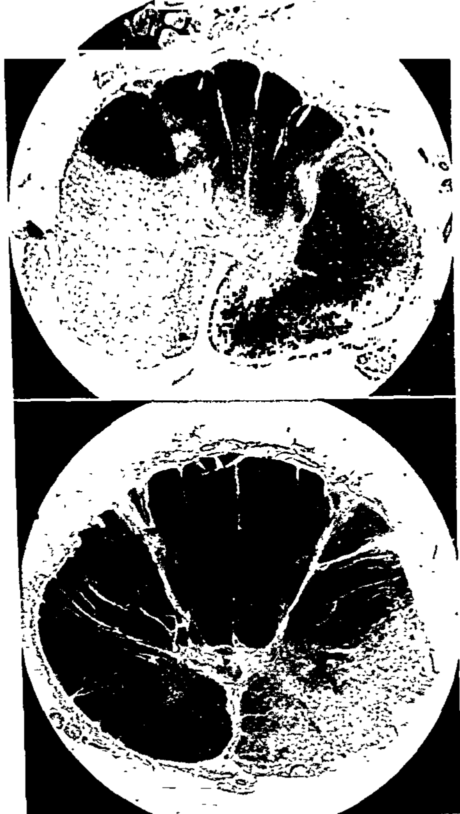


Fig. 68. Anterolateral cordotomy: Extent of incision in anterolateral column in relation to level of analgesia.

In both cases the cordotomy was made at the level of the second thoracic vertebra. In the patient whose cord is shown in A (*upper*), the level of analgesia rose to T3 dermatome, while in the more complete transection shown in B (*lower*), hypalgesia rose to T5, but complete analgesia only to T10. These findings substantiate our claim that there are wide variations in the distribution of the pain fibres in the anterolateral quadrant and in the number of spinal segments required for complete decussation.

These patients died seven weeks and 19 days after operation, respectively, from complications of their malignant disease. There were no complications that could be related to these extensive transections, except for hypotension in the patient illustrated in A, in whom an incision of similar extent had also been made on the other side of the cord two segments removed from this.

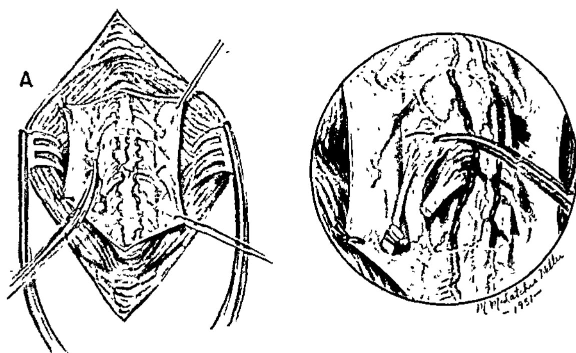


Fig. 67. Anterolateral cordotomy at upper thoracic level.
A. Details of exposure and rotation of spinal cord
B. Technique of rotating spinal cord by section and traction on dentate ligament and transection of anterolateral quadrant.

B.

Denticulate Ligament

Post Root

4 to 5mm

No II Knife Blade

Ant. Root

Ant. Spinal Artery

Frazier Cordotomy Hook

but as this is large and comes off at an angle of nearly 90 degrees, the cord is not easily rotated at this level. Because the motor cells of the phrenic nerve lie in the anterior horn from the third to the fifth spinal segments, it is not advisable to perform a cordotomy at this level. Kahn and Rand (1952) have recently presented an additional reason for avoiding cordotomy at the level of the enlargement for the brachial plexus. They have found that the anterior rootlets in this region may at some points emerge so close to the anterior median sulcus that an incision carried 2 mm. medial to such rootlets would damage the anterior spinal artery. On the other hand, the anterior rootlets in the upper thoracic cord up to and including T2 and in the upper cervical cord form a good, stable landmark, and incision should be carried at least 2 mm. medial to them. Therefore to relieve pain in the upper thorax or arm we prefer to place the tractotomy at the first or second cervical level, or even in the medulla when the arm and shoulder must be included.

As some surgeons still prefer to make their incisions at the midcervical level, we include the technical steps of this procedure. It differs in no essential manner from the upper thoracic operation, except that the cord is less easy to rotate on account of the larger size and tension of the cervical nerve roots, which run in a much less oblique direction. An improved view can be obtained if the whole cord is lifted dorsally as well as rotated to the maximal extent permissible. For a laminectomy at this level the patient may be placed in the standard prone position, with the head supported and flexed forward in a cerebellar headrest, or in the upright sitting position with the Craig headrest (Fig. 66B). The latter is somewhat more convenient for the surgeon and anaesthetist, but with the complete drainage of cerebrospinal fluid so much air enters the subarachnoid space and ventricles that the patient may complain of considerable headache when awakened for sensory testing. The fourth and upper half of the fifth cervical laminae are removed and the bone rongeured far out on the side where the anterior quadrant is to be transected. As the cord at this level is much broader than in its upper thoracic segments (average diameter 15 mm.), the preliminary incision should be made to a depth of 6 or even 7 mm. Since an incision just above the first big root of the brachial plexus, which lies near the upper border of the fourth cervical vertebra, is just below the anterior horn cells of the phrenic nerve, oedema of this area is likely to reduce the contraction of the diaphragm for the first few days after operation. For this reason a bilateral mid-cervical cordotomy should never be undertaken at one stage. Likewise, in patients with tumours of the thoracic outlet it is advisable to make sure that the diaphragm on the painful side is not paretic, as temporary weakening on the opposite side from operative trauma of the phrenic cells may seriously limit respiration. Reference to

with which Olivecrona (1947*B*) concurs. When pain is referred to the sacral segments it is important to be certain that the incision extends dorsally to the horizontal level passing through the origins of the dentate ligaments. The following observations bear out this statement: Falconer (personal communication, 1948) describes a pa[illegible] ving an upper thoracic cordotomy extended fr[illegible] e knee, sparing the lower lumbar and sacral segments. At reoperation the line of incision was carried right up to the dentate ligament "with the desired result." Kahn and Rand (1952) have recently presented four striking cases, in each of which after the initial cordotomy sacral analgesia was partially lacking and pain was referred to this area. In each of these patients reoperation *disclosed failure of the incision to reach dorsally to the origin* of the dentate ligament. Extension of the incision only into this zone sufficed to produce full sacral analgesia and relief of pain. Nulsen (1952) has corroborated this, and our patients' statements after insertion of tiny stimulating electrodes into this area of the cord confirm that it contains lumbosacral pain fibres. These findings controvert the contention of Hyndman and Van Epps (1939) that the zone of white matter just ventral to the dentate ligament has no pain fibres. We think that incisions extending ventrally from a point 2 mm. in front of the dentate ligament, as they recommend, will often miss such fibres.* However, we have evidence (p. 274) that sacral sparing may also ensue as a consequence of ipsilateral conduction of some pain fibres, and may not necessarily be due to failure to cut far enough dorsally. Foerster (1927*B*) and later Foerster and Gagel (1932) have contended that in a technically adequate unilateral cordotomy analgesia may be lacking in the anogenital region. In fact, this was the status in seven of eight cases cited in their first article. No postmortem evidence was adduced, however, that the lesion did in fact include the area just ventral to the dentate ligament. As stated above, the first incision is rarely deep enough and several further insertions of the hook may be required in order to obtain a level of analgesia up to the xyphoid or even the umbilicus, although on rare occasions it may reach the nipple line. If the tracts are to be cut bilaterally, two entire laminae are removed with parts of the ones above and below. The incisions in the cord are made *at least 2 cm. apart.*

In order to obtain analgesia to the xyphoid (eighth thoracic dermatome) it is best to centre the laminectomy on the second thoracic vertebra. To raise the level to the upper thoracic dermatomes, the incision of the cord can be made just above the first large root of the brachial plexus (C5),

---

*Oddly enough, in the diagram (Fig. 10 in their article) they illustrate the site of fibres from lower limb, groin, abdomen, and chest, but omit the anoperineal region and genitalia

in the cervical dermatomes, it is advisable to cut the ipsilateral upper cervical posterior spinal roots above C6 in addition.

In cases where the lower medulla has been exposed but the vascular pattern makes it difficult to cut the tract at this level, it has proved a simple matter to carry out the tractotomy as described above in the upper portion of the cervical cord, ventral to the highest fascicle of the dentate ligament and caudal to the first cervical root. Except for disagreeable paraesthesia over the opposite side of the body in two cases, we have had no serious complications in a number of cordotomies at this level. One was of particular interest, as the patient (Chap. XIII, Table XXI, Patient 2) was a professional rollerskater with thoraco-cervico-occipital neuralgia following repeated upper thoracic sympathectomies for Raynaud's disease. After a left-sided cordotomy at the second cervical segment in March, 1949, analgesia at first extended to C5; at the end of a year it remained complete to T1, while hypalgesia had receded from C3 to C5. It then became necessary to cut the other anterior quadrant (October, 1950), which gave a very similar result. At 11 months after the second cordotomy this good response was marred by a low-grade resistant cystitis unfortunately acquired after only a week of postoperative catheterization. At the end of two years her cystitis had cleared but analgesia remained complete only in the upper thoracic segments (see Fig. 78, p. 270). Elsewhere she could feel pricking sensations with the algesiometer set at a tension of less than 30 grams. Only a very low-grade hypalgesia persisted in the arms and right leg, where she complained of disagreeable paraesthesia. Appreciation of heat was still absent below the neck, but cold could be distinguished everywhere save in the limited area of analgesia. This extensive recovery of sensibility to cold and pain had taken place within the previous six months. It was noteworthy that after the first high cordotomy she was able to do fancy skating without any complaints referable to the operation, but at two years after the second she complained of poor motor control in the right leg. She fortunately never had any return of her original pain. Another patient (Chap. XVII, Table XXXIV, Patient 4) maintained complete analgesia of the five lower cervical and upper thoracic dermatomes at nine months. In making the cordotomy incision in this patient with postherpetic pain in the upper chest, the knife was inserted 1 mm. anterior to the dentate ligament in the hope of preserving some sensation in the lower half of the body. After 20 months she remained free of her former pain, with analgesia limited to the upper six thoracic dermatomes, hypalgesia of the lower neck and arm, and large areas of nearly normal sensation in the abdomen, buttock, and thigh.

In other recent experiences we have attempted to cut the pain tract at this level in such a selective manner that analgesia can be limited to the

Table III, Chap. IX, shows that our mortality after unilateral cordotomy has been somewhat greater at the cervical than at the thoracic level, although the three patients who died had such advanced malignant disease at the apex of the thorax that these figures may not be significant.

In order to raise the level of analgesia to include the brachial plexus, the anterolateral quadrant must be cut deeply at the highest cervical level. Here the average diameter of the cord is 12.5 mm. and the anterior quadrant must be incised to a depth of at least 6 mm. When it is necessary to obtain only a high thoracic level 5 mm. should suffice. We have found that cordotomy at this level can be carried out most easily in the upright sitting position (Figure 66B) but, as mentioned above, headache from air entering the meninges may distract the patient at the time of sensory testing, and there is always a potential risk of air embolism (Hamby and Terry, 1952). For this reason we generally prefer the lateral cerebellar position (Figure 66C) for thin-necked individuals in whom a normal degree of flexion of the head on the chest is possible. When this is used, it is most important to incline the table so that the heart and lower half of the body are below the head and neck; otherwise bleeding will be profuse from all planes of the incision, particularly from the epidural veins. The two upper cervical laminae are removed widely on the side of the tractotomy. When the dura is opened the absence of large posterior roots permits easy access to the dentate ligament. There is usually a well-defined slip at C2 and also at C1 where the suspensory ligament terminates. The absence of a posterior root at C1 and the relatively small sensory root of C2 permit a much better exposure of the anterolateral quadrant here than at lower cervical levels, where the cord is anchored and the surgeon's view obscured by much larger roots. As decussation of the crossed pyramidal tracts is completed within the first cervical segment, incision into the anterior quadrant at the uppermost rootlet of C2 will not injure these pathways.* One of us has even made the incision just caudal to C1 motor root without producing detectable weakness of the leg, although an up-going Babinski toe response was observed on the side of the incision in one individual.

The cordotomy is made exactly as at lower levels. It is of vital importance to test the extent of analgesia to ensure an adequate transection, particularly if the sensory level is to include the upper arm and shoulder area. Even with these precautions we have found it extremely difficult to maintain a permanent level of analgesia as high as the fifth cervical dermatome (see below). If loss of sensibility to pain must be maintained

*At our request Dr. Samuel Brendler, resident on the neurosurgical service at the Massachusetts General Hospital, has made serial sections of a number of human spinal cords It is clear from these that the pyramidal tracts have completed their decussation at the level of the most rostral fascicle of the second cervical posterior root

in the cervical dermatomes, it is advisable to cut the ipsilateral upper cervical posterior spinal roots above C6 in addition.

In cases where the lower medulla has been exposed but the vascular pattern makes it difficult to cut the tract at this level, it has proved a simple matter to carry out the tractotomy as described above in the upper portion of the cervical cord, ventral to the highest fascicle of the dentate ligament and caudal to the first cervical root. Except for disagreeable paraesthesia over the opposite side of the body in two cases, we have had no serious complications in a number of cordotomies at this level. One was of particular interest, as the patient (Chap. XIII, Table XXI, Patient 2) was a professional rollerskater with thoraco-cervico-occipital neuralgia following repeated upper thoracic sympathectomies for Raynaud's disease. After a left-sided cordotomy at the second cervical segment in March, 1949, analgesia at first extended to C5; at the end of a year it remained complete to T1, while hypalgesia had receded from C3 to C5. It then became necessary to cut the other anterior quadrant (October, 1950), which gave a very similar result. At 11 months after the second cordotomy this good response was marred by a low-grade resistant cystitis unfortunately acquired after only a week of postoperative catheterization. At the end of two years her cystitis had cleared but analgesia remained complete only in the upper thoracic segments (see Fig. 78, p. 270). Elsewhere she could feel pricking sensations with the algesiometer set at a tension of less than 30 grams. Only a very low-grade hypalgesia persisted in the arms and right leg, where she complained of disagreeable paraesthesia. Appreciation of heat was still absent below the neck, but cold could be distinguished everywhere save in the limited area of analgesia. This extensive recovery of sensibility to cold and pain had taken place within the previous six months. It was noteworthy that after the first high cordotomy she was able to do fancy skating without any complaints referable to the operation, but at two years after the second she complained of poor motor control in the right leg. She fortunately never had any return of her original pain. Another patient (Chap. XVII, Table XXXIV, Patient 4) maintained complete analgesia of the five lower cervical and upper thoracic dermatomes at nine months. In making the cordotomy incision in this patient with postherpetic pain in the upper chest, the knife was inserted 1 mm. anterior to the dentate ligament in the hope of preserving some sensation in the lower half of the body. After 20 months she remained free of her former pain, with analgesia limited to the upper six thoracic dermatomes, hypalgesia of the lower neck and arm, and large areas of nearly normal sensation in the abdomen, buttock, and thigh.

In other recent experiences we have attempted to cut the pain tract at this level in such a selective manner that analgesia can be limited to the

neck, arm, and upper thorax. Figure 69 illustrates such a result in a woman with carcinoma invading the brachial plexus. Instead of starting the incision at the level of the dentate ligament, the knife was inserted a short distance (1+ mm.) anterior to it. On testing, the analgesic zone extended from the chin and occiput down to the mid-thorax. Two weeks later analgesia was limited to the cervical and upper four thoracic dermatomes, as shown in the photograph. Unfortunately the patient subsequently reported



Fig 69. Anterolateral cordotomy at C2 spinal segment. Preservation of pain and temperature sensation below mid-thorax by sparing narrow strip of cord just anterior to dentate ligament

that some pain recurred at two months with further rostral recession of the analgesic area. This method of limited cordotomy deserves further study, but at present we feel that the results are too unreliable and that the entire tract had best be severed.

B. SPINOTHALAMIC TRACTOTOMY AT MEDULLARY LEVEL

Not infrequently the neurosurgeon is confronted by a persistent neuralgia which involves the dermatomes of the shoulder and neck to so high a level that adequate analgesia cannot be obtained with certainty by any form of cordotomy. In these circumstances the spinothalamic pain tract can be interrupted in the medulla or mesencephalon. Pain of this type is most often due to neuralgia arising after amputation at the shoulder, or to carcinomatous infiltration of the brachial plexus. As is well known, such conditions have been most difficult to relieve, even with extensive resection of the posterior cervical sensory roots. For some reason not yet fully explained, pain which fails to respond to rhizotomy can often be eliminated by interrupting the secondary sensory fibres (see pp. 381, 399).

Schwartz and O'Leary (1941) first advocated section of the spinothalamic tract in the lateral medulla at the level of the inferior olive, where it lies just medial to Gower's tract and ventral to the lowest rootlets of the vagus. Unfortunately their patient with advanced malignant disease failed to survive the operation for more than a few days, but analgesia and loss of temperature discrimination extended up into the neck without any obvious damage to other important structures. Soon after Schwartz's operation one of us (White, 1941) reported a successful case. This young woman, with an unbearable neuralgia of the neck, shoulder, and upper chest which followed multiple upper thoracic sympathectomies for recurring Raynaud's disease, has been completely relieved of her right-sided neuralgia for 10 years. Convalescence was complicated by a mild cerebellar ataxia, which eventually disappeared. In order to avoid this, White in his report recommended that the incision in the medulla be made at a more caudal level in order to avoid any possibility of injuring the inferior cerebellar peduncle and vestibular nuclei. Instead of making the tractotomy at the level shown in Figure 60A, we have since dropped the incision to just below the obex (Fig. 60B), which corresponds to Grant's modification of Sjöqvist's section of the spinal trigeminal tract. This has eliminated cerebellar ataxia, which was sometimes a troublesome factor after Sjöqvist's original operation as well. We have now carried out this procedure nine times with three fatalities but no other serious complications. One of the patients who died and another who had a very successful result, in whom the lesion was made by electrocoagulation, are not included in Table VIII; cases in which no more than two years have elapsed since operation are, for the most part, excluded from this book.

The operation is best performed with the patient in the lateral cerebellar position (Fig. 66C). The anaesthetist then has easy access to the patient's face, respiration is unhampered, there is free drainage of cerebro-

spinal fluid from the cisterna magna, and the surgeon has the clearest view of the operative field. A small inverted U incision is made on the side opposite to the pain, carried upwards and medially from the mastoid just above the attachment of the occipital muscles and then swung down the midline of the neck (Fig. 70A). In thin-necked individuals a slightly longer

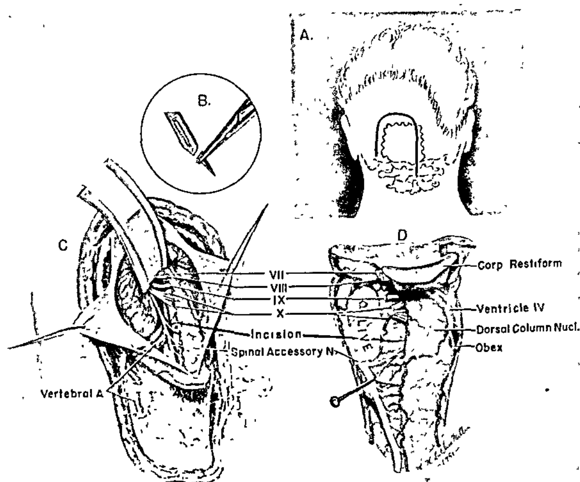


Fig 70. Technique of spinothalamic tractotomy in the medulla.
A Incision
B Broken-off knife-blade used to ensure accurate depth of incision to 6 mm.
C. Operative exposure showing relationship of medullary incision to obex, cranial nerves, and vertebral artery. The posterior cerebellar artery is not included because of the wide variations in its origins and course.
D. Enlarged lateral view of medulla.

midline incision will suffice. The attachment of the nuchal muscles is cut just below the occipital ridge, and the muscles separated in the midline and scraped off the occiput down to the foramen magnum and posterior arch of the atlas. The occipital bone is then trephined and rongeured away to expose the lower portion of the cerebellar hemisphere and a short distance across the midline. The foramen magnum should be opened widely

and the arch of the atlas removed as well. The dura and arachnoid over this region are opened widely and the cisternal fluid drained. The cerebellar tonsil can then be elevated to expose the lower end of the fourth ventricle and the side of the medulla (Fig. 70C). This gives access to the rootlets of the spinal accessory and vagus nerves as they emerge from the upper cervical cord and posterolateral sulcus of the medulla. It is now important to observe the position of the posterior inferior cerebellar and vertebral arteries, which at times makes it difficult to expose the lateral aspect of the medulla in front of the line of emerging rootlets of the eleventh nerve. With gentle manipulation and perseverance the medulla can usually be cleared at the desired site. The finer pial vessels at its side are ordinarily no more troublesome than in the standard cordotomy,* but occasionally it is not feasible to incise the pain tract anywhere in the zone between the level of the obex and 6 mm. caudal thereto. In these circumstances the incision must be dropped to a point just below the foramen magnum, at the level of the first fascicle of the second posterior root, where the decussation of the pyramidal tract is complete. In this case it is advisable to *remove the lamina of the axis vertebra as well.*

The incision in the medulla should be made from 0 to 6 mm. caudal to the obex, just anterior to the line of emergence of the upper rootlets of the spinal accessory nerve (Fig. 70B, D). At this point the spinothalamic fibres are overlain by the thin bundle of Gower's tract, as is the case in the cord. The pain tract extends medially to a depth of some 6 mm. It lies immediately ventral to the descending trigeminal root and is 4 mm. in width from front to back (Fig. 70D).

A good instrument for making the incision is the broken-off pointed tip of a No. 11 Bard-Parker knife blade protruding 6 mm. at a 90-degree angle from the jaws of a fine haemostat (Fig. 70B). This is inserted through the pia well *anterior to the line of spinal accessory roots to its full depth in the* transverse diameter, and then used to cut dorsally through a segment of medulla some 4 mm. in width (Fig. 71). If the patient is conscious at this moment he should feel a twinge of pain in the ipsilateral face as the most ventral fibres of the descending trigeminal root are reached at the line of emergence of the spinal accessory rootlets. We believe it is important to produce this sensation to be sure that the incision in the medulla is carried

*We have had one patient in whom there was such a network of small arteries overlying a large area of the lateral fossa of the medulla that we were unable by gentle blunt displacement to clear any place sufficient for the incision. A tiny cottonoid pledget soaked in 1:1000 epinephrin chloride was left over the area to control a small oozing vessel, and the arch of the atlas and lamina of the axis were removed preparatory to a resort to cordotomy. The cottonoid pledget on the side of the medulla was then removed, and to the operator's gratification the vessels were found blanched white over an area just large enough to permit the incision as originally planned.

far enough posteriorly. It is best to insert the Frazier cordotomy hook into the incision to ensure that the most ventral and medial fibres have been divided, and then to test the level of analgesia. If pain is still felt in the shoulder and neck, the incision should be deepened a millimeter and carried more posteriorly as well.



Fig. 71 Cross section of medulla after right spinothalamic tractotomy.
The incision on the right side of the medulla just below the obex was made to the correct depth and ventral extent, but was carried further dorsally than necessary into the area of the descending trigeminal tract and its nucleus. The extent of an ideal incision is marked in ink on the left side.

This patient (No. 5, Table VIII), who had an extensive fibrosarcoma of the left neck with pulmonary metastases and left vagal paralysis, had postoperative difficulty in swallowing and died on the second day in a convulsive seizure. He had contralateral analgesia to the chin (C2 dermatome) and ipsilateral analgesia over the area supplied by the ophthalmic division of the trigeminus His pain was relieved. Death was probably due to postoperative oedema of the right nucleus ambiguus in addition to vagal paralysis from invasive tumour in the left side of the neck.

The segmental arrangement of the spinothalamic tract at this level is somewhat similar to that in the spinal cord, with the sacral fibres most superficial and the cervical most deeply situated, but D'Errico (1950) has produced pretty convincing evidence that some of the cervical fibres lie posteriorly rather than anteriorly, as had been formerly supposed. On several occasions when he was cutting the tract under local anaesthesia he found no further rise in the sensory level on cutting deeper than 5 mm., but analgesia rose to the chin when he extended the incision 1 mm. more

posteriorly, and the patient experienced pain in the ipsilateral face from contact with the descending trigeminal root. When the incision has been properly performed there should be some analgesia in the ipsilateral face, especially in the ophthalmic division, and complete analgesia of the contralateral side of the body including a variable portion of the chin and occiput.

We have observed no more tendency for the incision to bleed than after an ordinary cordotomy and have had no serious complications from difficulty in swallowing or respiratory or motor weakness, except in Patient 5 (Table VIII, p. 277), where there was pre-existent paralysis of the opposite phrenic and vagus nerves from pressure of the tumour in the thoracic apex. If there is paralysis of the vagus, a tracheotomy should be performed preoperatively, because the bulbar incision on the opposite side may lead to transitory severe difficulties with the airway and aspiration of food or fluid associated with swelling in the region of the nucleus ambiguus. Bilateral tractotomy should never be undertaken, at least in a single stage. This has been attempted on several occasions by Crawford (1947) with a high mortality from difficulty with swallowing and resultant inhalation pneumonia. Closure of the incision and postoperative care differ in no way from the standard procedures employed in cerebellar operations.

We have explored the possibility of making electrical lesions in the brain stem in an effort to utilize the valuable techniques so effectively employed on experimental animals by Ranson, Magoun, and other neurophysiologists. Since the pain fibres from the cervical and upper thoracic segments probably lie at a depth of 3 to 6.5 mm., we hoped to avoid unnecessary damage to the surface of the medulla and to eliminate the need for dividing any pial vessels. In addition we hoped that the use of a unipolar [illegible] nt for making the lesion would decrease [illegible] within the central neuraxis by coagulating any blood vessels within its range. In attempting mesencephalic tractotomy according to Walker's technique we have divided arteries of significant size within the midbrain, a complication which we have not seen after incising the bulb or cord. The arterial blood flow emerging from within the incision made by a knife blade has been difficult to arrest without major damage. Consequently we have made lesions electrically in the bulb in four patients and in the mesencephalon in one. Each was awake during the time of passage of the current and in four of the five patients there was no discomfort or untoward behaviour.

Nichrome electrodes were provided for us by Professor H. W. Magoun of the University of California, to whom we are greatly indebted. These consisted of No. 20 gauge wire covered with insulating varnish except for 1 mm. at the bare tip. This electrode was made the anode and the other

electrode (at which more gas forms when the two are placed in saline) was attached to a large metal plate against the patient's skin. Current was delivered by the Goodwin-Stein "lesion maker," which provides a steady source of direct current whose value is constantly obtainable from a milliammeter in the circuit. This was always maintained at 3 milliamperes; only the duration was varied.

In *Paul S.* (MGH U-701400) the electrode was inserted into the bulb just ventral to an emergent spinal accessory rootlet at the exact cross-sectional level of the obex. The current was passed for 1 minute with the point 5 mm. deep; for 1.5 minutes, 3.5 mm. deep; and for two minutes, 2.5 mm. deep. Analgesia was then present on the opposite side only from the costal margin down, so the electrode was inserted to 6 mm. As the last mm. of the electrode was entering, the patient complained of pain in the contralateral neck, but passage of current for three minutes caused no sensation. (Total 6.5 min. at 3 ma.) However, he then had analgesia right up to the lower border of the ramus of the mandible. This receded to the C4 segment 10 months later, leaving profound hypalgesia over C2 and C3.

In *Leon F.* (MGH U-713019) the electrode at the same site in the bulb was used first to carry the 30/sec. 1 millisecond square wave signal from a Grass stimulator to see if we could utilize this method of checking the electrode position. At the threshold of 2 volts a diffuse sensation over the whole body "like a little electric shock" was produced; this was not more sharply localized at 5 v., so that no precise information as to the site of electrode placement was derived. At this same spot (5 mm. deep) application of the lesion-making current for 2.5 minutes produced analgesia on the opposite side everywhere from the C5 segment down. After another two minutes at 6 mm. depth the analgesia rose only one more segment. Another minute at 6 mm. depth did not change the analgesia. (Total 5.5 min. at 3 ma.) During the second period of application of current the patient complained rather half-heartedly of a diffuse shock-like sensation throughout much of his body. Pulse and blood pressure dropped markedly during each of the three periods of application of current, but rose nearly to the previous levels each time before or just after the end of this period. During the two months which this man survived he was free of his pain, which had been in the shoulder and upper limb, and maintained analgesia into the C5 segment. He showed at postmortem a well placed lesion 4 mm. in diameter with its inner border almost reaching the medial lemniscus.

The next two experiences were discouraging:

In *Sarah S.* (MGH U-402996), an unusually cooperative woman on the operating table, the point of the electrode was inserted at the same spot as in the two previous cases. At a depth of 5.5 mm. current for three minutes caused no demonstrable hypalgesia, and at a depth of 6.5 mm. for another three minutes it still yielded no loss to pin-prick. During the making of a second lesion the blood pressure rose gradually from 150/70 to 200/80 over

five readings in the three minutes, but there were no subjective sensations. The electrode was withdrawn till its point was only 3.5 mm. deep, and after another 3 ma. for three minutes there was profound hypalgesia confined to the contralateral arm. With the point of the electrode 2.5 mm. deep a final three minutes yielded analgesia of the arm and chest, high-grade hypalgesia of the flank, and slight hypalgesia of the lower limb. (Total 12 min. at 3 ma.) About 90 minutes were devoted to this lesion-making and testing phase of the operation, and we are confident of the reliability of the responses. Testing on the first to sixth postoperative days showed much more extensive analgesia from just above the clavicle over all lower segments contralateral to the lesion and complete relief of pain till death on the seventh postoperative day. The postmortem showed an essentially nonhaemorrhagic lesion, larger than necessary, involving the upper half of the inferior olive as well as the appropriate region of the reticular formation just dorsal to this; it was 6 mm. wide by 5 mm. high in the cross-section at which it was maximal. It seems likely that the additional destruction of bulbar tissue contributed to her death from extensive carcinoma. A striking feature here was the long delay in development of analgesia following the passage of the current.

Antonio S. (Rhode Island Hospital) was unable to tell us where he felt pain when stimulated with an electrode tip 6 mm. deep in his bulb at the cross-sectional level of the obex. When we changed to the lesion-making current, bringing it up rapidly to 3 ma., as we had done in each previous case, the patient abruptly extended all four limbs. They relaxed when the current was promptly switched off. The electrode position seemed to be correct, so the current was raised to 3 ma. gradually over 20 seconds and held there for 110 seconds. The patient made no special movements and there were no striking changes in blood pressure, pulse, or respirations. However, he was much less responsive to testing after this. Two more lesions were made for two minutes each at depths of 4 and 2 mm. respectively. (Total 6 min. at 3 ma.) Following these lesions the patient remained stuporous and died a few days later. Autopsy disclosed a massive, deeply haemorrhagic spherical lesion 9.5 mm. in diameter occupying the inferior three-fifths of one side of the medulla. At the cross-sectional level of the obex the centre of the lesion was about 5 mm. deep. The surface of the medulla looked normal, so that bleeding started deeply at the electrode site. There was no inkling of this at the time the electrode was withdrawn.

Prior to this operation we used our electrode on *Jeannette* S. (MGH U-701367) for a mesencephalic tractotomy, inserting it 4 mm. deep 1 mm. dorsal to the lateral mesencephalic sulcus. Interrupted square wave electrical stimuli here at up to 10 v., 30 per second, 1 millisecond duration, caused no sensation of pain anywhere. The direct current was then applied for two minutes at 3 ma. The electrode was next shifted to two other positions (1 mm. ventral and also 1 mm. deeper than the original point), where a similar current was again applied for two minutes She then showed only hypalgesia of

electrode (at which more gas forms when the two are placed in saline) was attached to a large metal plate against the patient's skin. Current was delivered by the Goodwin-Stein "lesion maker," which provides a steady source of direct current whose value is constantly obtainable from a milliammeter in the circuit. This was always maintained at 3 milliamperes; only the duration was varied.

In *Paul S.* (MGH U-701400) the electrode was inserted into the bulb just ventral to an emergent spinal accessory rootlet at the exact cross-sectional level of the obex. The current was passed for 1 minute with the point 5 mm deep, for 1.5 minutes, 3.5 mm. deep; and for two minutes, 2.5 mm. deep. Analgesia was then present on the opposite side only from the costal margin down, so the electrode was inserted to 6 mm. As the last mm. of the electrode was entering, the patient complained of pain in the contralateral neck, but passage of current for three minutes caused no sensation. (Total 6.5 min. at 3 ma.) However, he then had analgesia right up to the lower border of the ramus of the mandible. This receded to the C4 segment 10 months later, leaving profound hypalgesia over C2 and C3.

In *Leon F.* (MGH U-713019) the electrode at the same site in the bulb was used first to carry the 30/sec. 1 millisecond square wave signal from a Grass stimulator to see if we could utilize this method of checking the electrode position. At the threshold of 2 volts a diffuse sensation over the whole body "like a little electric shock" was produced, this was not more sharply localized at 5 v., so that no precise information as to the site of electrode placement was derived. At this same spot (5 mm. deep) application of the lesion-making current for 2.5 minutes produced analgesia on the opposite side everywhere from the C5 segment down. After another two minutes at 6 mm. depth the analgesia rose only one more segment. Another minute at 6 mm depth did not change the analgesia. (Total 5 5 min. at 3 ma.) During the second period of application of current the patient complained rather half-heartedly of a diffuse shock-like sensation throughout much of his body. Pulse and blood pressure dropped markedly during each of the three periods of application of current, but rose nearly to the previous levels each time before or just after the end of this period. During the two months which this man survived he was free of his pain, which had been in the shoulder and upper limb, and maintained analgesia into the C5 segment. He showed at postmortem a well placed lesion 4 mm in diameter with its inner border almost reaching the medial lemniscus.

The next two experiences were discouraging:

In *Sarah S.* (MGH U-402996), an unusually cooperative woman on the operating table, the point of the electrode was inserted at the same spot as in the two previous cases. At a depth of 5.5 mm. current for three minutes caused no demonstrable hypalgesia, and at a depth of 6.5 mm. for another three minutes it still yielded no loss to pin-prick. During the making of a second lesion the blood pressure rose gradually from 150/70 to 200/80 over

We report these findings in some detail as a warning to others and an indication of the urgent necessity for improving the methods. We do not intend to imply from the account of our experiences in man any criticism whatsoever of the use of this technique for studies in experimental animals, where control of the precise size of the lesion is of less importance, and haemostasis far less of a problem. We are greatly indebted to Drs. H. W. Magoun, W. S. McCulloch, and R. S. Snider for valuable tutelage in this field.

C. TRACTOTOMY IN THE PONS

Serra and Neri (1936) sought to divide secondary afferent pathways for pain by inserting an electrode into the pons in front of the trigeminal rootlets. In their lone case, which they report briefly, analgesia was said to have been produced in the second to fifth cervical segments by the operation. The passage of the electrocoagulating current caused "a frightful cry of pain" from the patient but no significant change in vital signs.

Dogliotti (1938), through a supratentorial approach, incised or electrocoagulated pain pathways in the uppermost pons or lower mesencephalon in four patients. He inserted his instrument 4.5 mm. deep into the lateral mesencephalic sulcus. Cerebral oedema killed one patient 36 hours after operation. The other three used "no more or very little morphine during the months of remaining life." A complete contralateral hemianalgesia was present in two of the three patients at first; there were early diffuse unpleasant paraesthesias, which were later confined to the contralateral side. Clovis Vincent (reported by Le Beau, Daum, and Forjaz, 1948) attempted in eight patients to electrocoagulate the quintothalamic bundle in the rostral portion of the pons. Utilizing the approach of Dandy to the trigeminal root, he inserted his electrode into the pons immediately above and a little in front of the trigeminal nerve to a depth of 2 cm. At this juncture the patients sometimes complained of facial pain. Four of these patients died on the first or second postoperative day, and in two of them haemostasis had been such a problem that the actual tractotomy was not attempted. Of the survivors two had had postherpetic neuralgia and two a facial neuralgia characterized by constant pain. Since three of these patients had undergone interruption of primary trigeminal pathways before the tractotomy, the additional effect on sensation produced by this operation could not be tested. In the fourth patient an anaesthesia for all modalities was achieved in the first trigeminal division; in the lower two divisions a pin-prick was often described as a normal thermal sensation. Relief of pain in the postherpetic pair was only fair, but in the other two it was almost complete. These results may encourage other neurosurgeons to try to develop the approach to the secondary afferent fibres in the pons. A fea-

her contralateral forearm. The electrode was inserted 2 mm. more dorsally to a depth of 4 mm. and passed ventrally so readily to join the previous tract that no current was applied. (Total 6 min. at 3 ma.) Later that day she showed analgesia from the top of the head to the costal margin; by two weeks later there were some hypalgesic areas in this zone, but she remained almost free of her original pain in the head, neck, and shoulder until death five months after operation.

Although lesions can be made painlessly by this technique, the lack of correlation in sensory loss found on testing at operation and afterwards is a serious drawback. In view of the appalling inconsistency in the size of these lesions in the bulb in man, Dr. Vernon H. Mark has rechecked the precision of this technique in the brains of experimental animals. He has found that a change to stainless steel electrodes (otherwise similar to those of nichrome) enabled him to study the deposition of the metal in the tissues by means of iron stains without interfering with the usual histologic methods. He made several series of electrical lesions using the same source of current; in one group the duration was varied from 10 seconds through five increments up to four minutes; in the other group the milliamperage was varied from one to five. In a total of 73 lesions in the cerebral hemispheres of 11 cats and two dogs, the variability in the size of these lesions was even greater than that seen in our human material, and constancy was not achieved even with short durations of current. For example, at 5 ma. and 10 seconds one lesion was 4.0 x 7.2 mm. in maximal cross-sectional area, whereas another lesion at these same parameters measured 1.4 x 1.5 mm. in maximal extent. At longer durations the lesions varied even more; at 3 ma. and two minutes the largest lesion measured 33 x 6.4 x 12 mm., and the smallest 7 x 4 x 3.2 mm. Although the presence of tiny blood vessels in the lesions tended to result in their assuming erratic shape and extent, even those lesions confined to avascular portions of white matter showed variability of several hundred per cent in area. Carpenter and Whittier (1952) have published their findings after similar experiments. Their even more thorough exploration of various electrical techniques for producing lesions has demonstrated similar inconstancy, e.g., at 5 ma. and 15 seconds they find some lesions four times the size of others. They consider unipolar anodal technique (the method we used) to be less variable than other electrical methods.

More recently Mark and Sweet have been using radiofrequency signals at 2000 kilocycles to produce small circumscribed lesions in the brain of both cats and man; we are tentatively under the impression that this type of electrical "lesion maker" yields more consistent results. The destructive effect is presumed to arise solely from heat appearing in the immediate vicinity of the monopolar electrode.

what more rostrally at the level of the posterior margin of the superior colliculus. Here the lateral sulcus is less difficult to expose and identify. The surgical approach to the midbrain is not an easy task and requires special precautions to obtain accurate placement of the incision, as well as care in retraction of the temporal lobe and avoidance of injury to neighbouring structures such as the veins and trochlear nerve. For anaesthesia we have preferred local supplemented by light Pentothal with nitrous oxide and oxygen, so that the patient can be awakened and tested on the operating table. Verification of the area of analgesia is even more desirable here than after thoracic or cervical cordotomy.

The surgical approach of Walker (1942A) consists of an occipitoparietal scalp flap starting below and just lateral to the occipital protuberance. This is carried upwards 10 cm. close to the midline and then laterally and downwards to end at the mastoid (Fig. 72). Four trephine openings are made, the lower pair 1 cm. below the lateral sinus, the upper 6 to 7 cm. above. The bone between the medial, upper, and lateral burr holes is cut with a Gigli saw and the base fractured, so that the flap is hinged down on the attachment of the occipital muscles. In order to have a clear view it is essential to expose the dura to the level of the tentorium. The mastoid air cells should not be opened, and precautions should be taken not to injure the transverse or sigmoid sinuses. The dura is then opened and turned down as close to the tentorium as the transverse sinus will permit.

This operative approach beneath the occipital lobe at best permits a relatively limited exposure, and every advantage must be gained by rotating the head and tilting it downwards so that gravity will aid in drawing the brain away from the tentorium. Exposure will be greatly improved if the cerebrospinal fluid has been effectively drained by lumbar puncture from the start of the operation. The under surface of the occipital lobe is gently retracted, using cottonoid strips to protect the cortex and with extreme care to avoid tearing bridging veins from the under surface of the temporal lobe. The tentorium is followed forwards to the incisura. It is usually necessary to coagulate and cut a few bridging veins, but every effort should be made to preserve the main vein of Labbé, which drains the lower portion of the temporal lobe into the lateral sinus. Sacrifice of this important vein may lead to oedema of the temporal lobe, with ischaemia of its optic radiations and a stuporous state after operation (Guiot, 1948). When the incisura has been visualized, a better view of the lateral sulcus and the posterolateral aspect of the mesencephalon can be obtained by cutting the tentorium (Fig. 72-2).

With this membrane split the trochlear nerve and arachnoid covering the dorsolateral surface of the midbrain are exposed. To gain a clear view

sible technique to achieve consistent analgesia may be worth seeking, since there is a possibility that interruption here will carry less chance of paraesthesia than one finds after mesencephalic tractotomy.

D. TRACTOTOMY AT MESENCEPHALIC LEVEL

The pain tracts from the entire opposite side of the body can be interrupted by incising in the neighbourhood of the lateral lemniscus in the mesencephalon. Here the secondary trigeminal and other faciocephalic fibres have joined the spinothalamic tract, and it is possible to divide the entire group of pain-conducting axones just before they enter the nucleus ventralis posterior of the thalamus without injuring other important pathways. Dogliotti (1938) first took advantage of this anatomical juxtaposition, making his incision at the most rostral level of the pons. Walker (1942B), who has made such careful anatomical studies of the localization of the spinothalamic and secondary trigeminal fibres in the brain stem and thalamus, has found that it is preferable to make the incision some-

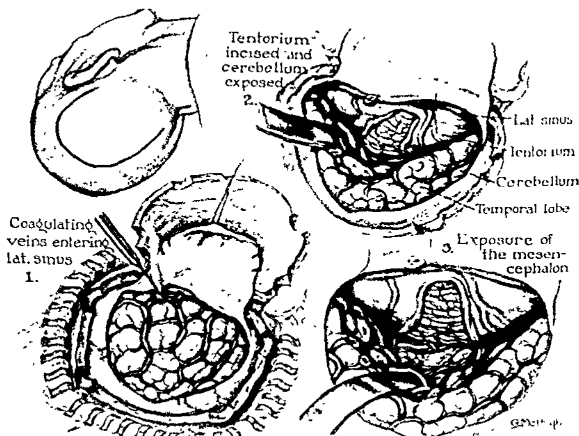


Fig. 72. Mesencephalic tractotomy: Walker's illustration of technical steps in exposure of dorsolateral surface of mesencephalon.

From Walker: *Arch. Neurol. & Psychiat.*, 1942A Courtesy, American Medical Association, Chicago.

what more rostrally at the level of the posterior margin of the superior colliculus. Here the lateral sulcus is less difficult to expose and identify. The surgical approach to the midbrain is not an easy task and requires special precautions to obtain accurate placement of the incision, as well as care in retraction of the temporal lobe and avoidance of injury to neighbouring structures such as the veins and trochlear nerve. For anaesthesia we have preferred local supplemented by light Pentothal with nitrous oxide and oxygen, so that the patient can be awakened and tested on the operating table. Verification of the area of analgesia is even more desirable here than after thoracic or cervical cordotomy.

The surgical approach of Walker (1942A) consists of an occipitoparietal scalp flap starting below and just lateral to the occipital protuberance. This is carried upwards 10 cm. close to the midline and then laterally and downwards to end at the mastoid (Fig. 72). Four trephine openings are made, the lower pair 1 cm. below the lateral sinus, the upper 6 to 7 cm. above. The bone between the medial, upper, and lateral burr holes is cut with a Gigli saw and the base fractured, so that the flap is hinged down on the attachment of the occipital muscles. In order to have a clear view it is essential to expose the dura to the level of the tentorium. The mastoid air cells should not be opened, and precautions should be taken not to injure the transverse or sigmoid sinuses. The dura is then opened and turned down as close to the tentorium as the transverse sinus will permit.

This operative approach beneath the occipital lobe at best permits a relatively limited exposure, and every advantage must be gained by rotating the head and tilting it downwards so that gravity will aid in drawing the brain away from the tentorium. Exposure will be greatly improved if the cerebrospinal fluid has been effectively drained by lumbar puncture from the start of the operation. The under surface of the occipital lobe is gently retracted, using cottonoid strips to protect the cortex and with extreme care to avoid tearing bridging veins from the under surface of the temporal lobe. The tentorium is followed forwards to the incisura It is usually necessary to coagulate and cut a few bridging veins, but every effort should be made to preserve the main vein of Labbé, which drains the lower portion of the temporal lobe into the lateral sinus. Sacrifice of this important vein may lead to oedema of the temporal lobe, with ischaemia of its optic radiations and a stuporous state after operation (Guiot, 1948). When the incisura has been visualized, a better view of the lateral sulcus and the posterolateral aspect of the mesencephalon can be obtained by cutting the tentorium (Fig. 72-2).

With this membrane split the trochlear nerve and arachnoid covering the dorsolateral surface of the midbrain are exposed. To gain a clear view

of the regional blood vessels (posterior cerebral and superior cerebellar arteries) and the lateral sulcus it is necessary to tease away the arachnoid. Large amounts of fluid drain from the ambient cistern and must be sucked away. The branches of the venous plexus must now be brushed aside with fine cottonoid tufts to expose the lateral sulcus and the brachium of the inferior colliculus. Usually it is not too difficult to clear the vessels from the area to be incised, but occasionally this may present a problem. For

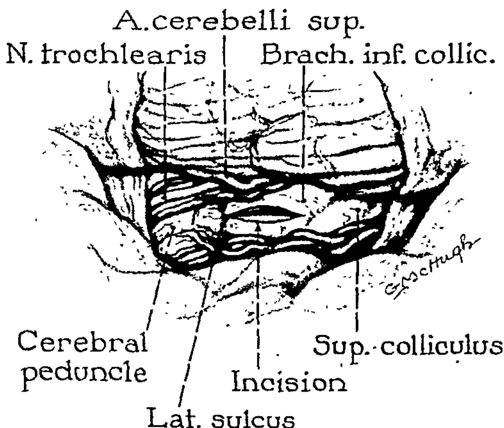


Fig. 73. Mesencephalic tractotomy. Walker's illustration of position and extent of incision.
From Walker: *Arch. Neurol. & Psychiat.*, 1942A. Courtesy, American Medical Association, Chicago.

use in this eventuality we are hoping that an accurately controllable method for making the desired lesion by employing encapsulated beta radiation will emerge from work now in progress by Dr. James B. Campbell.

The tractotomy, according to Walker (1942A),* "is made at the level of the posterior margin of the superior colliculus from the lateral sulcus . . . across the brachium of the inferior colliculus to the base of the superior

---

*Walker, A. E: Relief of pain by mesencephalic tractotomy. *Arch. Neurol. Psychiat*, 1942, *48*:865-883, courtesy of the American Medical Association, Chicago

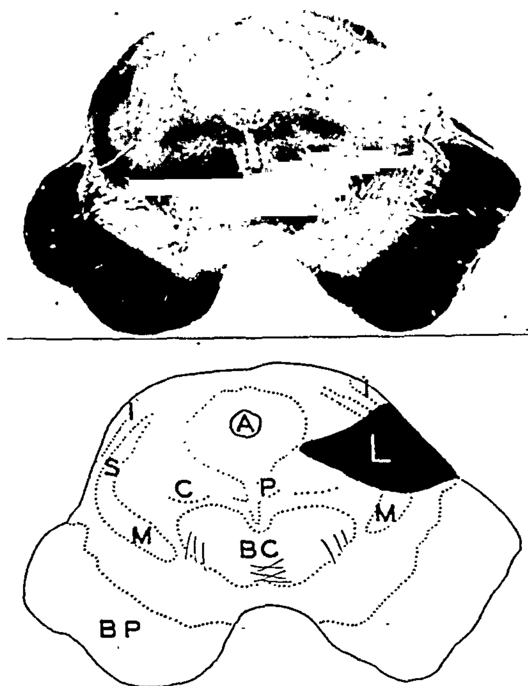


Fig. 74. Mesencephalic tractotomy: Photomicrograph and anatomical diagram of mesencephalon.

"An untouched photomicrograph of a section at the point of maximum damage to the mesencephalon (immediately caudal to the superior colliculus) and a sketch of the section with the tracts labeled. A, aqueductus sylvii, BC, brachium conjunctivum; BP, basis pedunculi, C, tractus centralis tegmenti, I, brachium colliculi inferioris; L, lesion, M, lemniscus medialis, P, fasciculus longitudinalis medialis, S, tractus spinothalamicus."

Figure and legend from Walker: *Arch Surg*, 1942B. Courtesy, American Medical Association, Chicago.

colliculus. The incision (Fig. 73), 5 mm. in depth, is made by a sharp-pointed straight knife. Such a knife is necessary, since the operator's line of vision is at right angles to the lateral surface of the mesencephalon. The knife should be passed through the incision a second time to be sure that all fibers have been cut. No bleeding is usually encountered." The area which Walker (1942B) cuts and its relations with other structures are shown in Figure 74.

The somatotopic arrangement of the fibres in the spinothalamic tract, from the experience of Walker and others including ourselves, is probably the same in man as that so clearly illustrated by Walker (1942C) in the macaque. His photomicrographs of the mesencephalon at the level of the superior colliculus illustrate the position of the fibres undergoing Marchi degeneration after experimental lesions of the spinal trigeminal nucleus and a series of midline myelotomies at different levels of the cord. It is evident that the fibres from the face and neck lie within and just dorsal to the medial lemniscus, while those from the lower segments lie further dorsally and medial to the brachium of the inferior colliculus. Therefore, unless the incision is carried well up onto the lateral slope of the superior colliculus, the analgesia will include only the upper portion of the body. It has proven more difficult to secure lasting analgesia by incision at this level than in the bulb or cord, and extremely disagreeable paraesthesias have marred some otherwise successful results (K. G. McKenzie, personal communication).

E. SECTION OF LISSAUER'S TRACT

As the posterior roots enter the spinal cord a group of fine medullated and nonmedullated fibres diverges from them and runs longitudinally at the apex of the posterior column of grey matter to form the tract of Lissauer. Ranson and Billingsley (1916) cut these fibres in cats as they left the posterior roots, and then found that stimulation of the central end of the divided posterior root no longer caused struggling suggestive of pain. In other cats all but the fibres entering Lissauer's tract were cut; the same type of stimulation then caused responses which were taken to indicate the presence of pain.

On the basis of these findings in animals Hyndman (1942) tried the operation in five patients. In three of them it was supplementary to cordotomy; in the other two he made no incision elsewhere into the cord. The cuts were made to a depth of 2 mm. and straddled the line of entry of the posterior rootlets (Fig. 75). The knife point was inserted medial to the posterolateral sulcus marking the entrance of the rootlets and was carried for 2 mm. laterally. These incisions were said to produce loss of pain sensa-

tion over the three cervical segments immediately below the level at w they were made. In the three patients who also had cordotomy on the o site side at the same segment, T1, the combined result was to bring the level of analgesia right up to the lower part of the T2 dermatome in two of them. In the third hypalgesia was produced from T1 to T7, with analgesia below that. Hyndman and Wolkin (1943) mention obtaining similar results in a total of nine patients. If this additional small incision could be counted

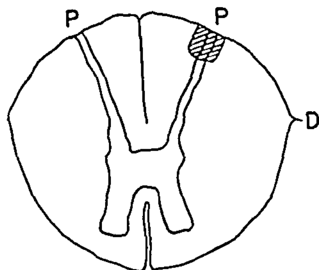


Fig. 75. Section of Lissauer's tract.
The cross-hatched area indicates the site of incision for the division of the dorsolateral fasciculus of Lissauer (marginal zone of Waldeyer), as recommended by Hyndman. P - posterolateral sulcus. D - origin of denticulate ligament (placed more posteriorly by Hyndman than by most observers).
Redrawn from Hyndman: *J. Internat Coll. Surgeons*, 1942, by permission of the editor.

on to raise the level of analgesia, it would be most useful when carried out at the C1-2 segment as an adjunct to cordotomy for treatment of pain in the neck and arm. Unfortunately in two patients in whom Hyndman (1942, 1948) made such a cut into the cord at the C3 segment, no impairment of touch, pain, or temperature sensibility occurred in the ipsilateral arm or chest.

It is not surprising to us that a single transverse incision into Lissauer's tract should cause an inconstant band of sensory loss, since the fibres in it do not all pass upward as Hyndman states. Instead they bifurcate, one branch passing upward, the other downward, and each branch gives off collaterals which pass into the grey matter of the posterior horn (Bok, 1928, p. 534). Indeed, in view of this diffuse fanning of the pain pathways as they enter the cord, it is perhaps astonishing that Hyndman noted any sensory loss at all after a transverse incision into this tract.

F. MYELOTOMY OF THE COMMISSURE

The secondary pain-conducting axones, whose cells are situated in the posterior spinal horn, cross in the anterior commissure of the cord and ascend in the opposite spinothalamic tract. According to standard neuroanatomical teaching, this decussation is completed within two spinal segments,

but evidence presented in Figure 68B makes it doubtful that this is consistently the case.

With this concept in mind, Leriche suggested that a longitudinal midline incision between the columns of Goll would result in bilateral bands of analgesia corresponding with the extent over which the decussating fibres are interrupted. No other axones than those conducting pain and thermal sensation cross the midline of the spinal cord, and this operation therefore creates the same effect as a syringomyelic cavity in its early stages of development. The operation was first performed in 1928, but not published by Leriche (1936) until eight years later. Putnam (1934), who did not know of Leriche's work, was the first to perform the operation in this country. As he feared that an actual incision would result in ischaemia of the dorsal columns from injury of the delicate posterior spinal vessels, Putnam attempted to interrupt the decussating fibres by passing needles through avascular areas in the midline and working them up and down in the central plane of the cord. The bilateral analgesia of the arms which was produced by this manoeuvre at the cervical enlargement was of only brief duration because many fibres were not severed but only displaced and bruised. As a result the method was soon abandoned in this country.

French surgeons, however, have found it possible to incise and split the lumbar enlargement of the cord and thereby produce lasting interruption of pain in the perineum, pelvis, and lower extremities. We have had no personal experience with this operation, but Mansuy, Lecuire, and Acassat (1944) and Wertheimer and Sautot (1949) in Lyons believe that it is preferable to anterolateral cordotomy for the relief of pain in pelvic malignancies. They have performed commissural myelotomy in 69 cases and reported the results in 59. There have been four deaths and only six instances of transitory urinary retention. Complaints of postoperative radicular pain not unlike that often experienced after anterolateral cordotomy were made by 18 patients, but this persisted in only two. Entire freedom from complaints was reported by 29 patients and 11 others were sufficiently relieved to require no further narcotics. There was only slight benefit in six and 13 were failures. Some were followed up to five years. The degree of sensory loss in Wertheimer's patients seems to have been so variable that one would doubt that all the decussating fibres had been cut.

The technique of this operation is well described in the monograph of Guillaume, de Sèze, and Mazars (1949). The level of laminectomy depends on the knowledge of the spinal nerves involved and their entry into the cord. Owing to the increasingly oblique course of the lower spinal roots, the tenth thoracic enters the spinal cord at the upper border of the eighth thoracic vertebra and the sacral roots at the level of the last thoracic and first lumbar (Fig. 76).

The level and extent of laminectomy are based on these anatomical principles. Guillaume *et al.* recommend the use of local anaesthesia so that the proper roots can be identified by mechanical stimulation. The extent of the myelotomy and its level must be worked out in this fashion,

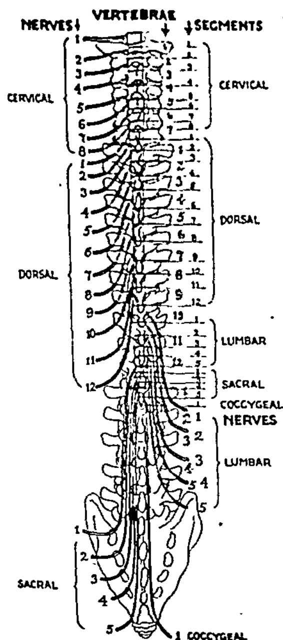


Fig. 76. Anatomical relationship between the spinal nerves, the segmental levels in the cord, and the vertebrae.
From Elsberg, 1911. Courtesy, Paul B Hoeber, Inc., New York.

while it is borne in mind that the decussation of the secondary axones takes place several segments rostral to the entry of the spinal roots. A laminectomy and longitudinal myelotomy extending over the last three thoracic vertebrae should therefore suffice to obtain analgesia over most of the area supplied by the lumbosacral plexus. Owing to the condensation of rootlets entering the lowest spinal segments, proper placement of this incision, as Guillaume admits, is not an easy matter and we advise exact identification

of the twelfth thoracic vertebra by means of a metal marker and preoperative x-ray. The French are in agreement that the operation is too dangerous to use in the upper segments of the cord, and that the extent of the incision is best limited to three vertebrae.

According to Guillaume *et al.*, the posterior longitudinal blood vessels can be very gently mobilized after cutting the pia and drawn to one side, so that the median sagittal plane between the posterior columns can be entered. In placing the incision every effort must be made not to deviate from the midline. Tiny branches of the anterior spinal artery are encountered, but bleed little. The myelotomy must be made deep enough to divide the anterior commissure, but with every possible precaution not to injure the anterior spinal artery. If local anaesthesia is used, the exact level and extent of analgesia can be controlled by sensory examination. In our experience the pia over the posterior columns is extremely sensitive to tactile stimuli. If the patient complains of pain, this can be controlled by a brief application of a cotton pledget soaked in 2 per cent procaine or by subpial injection of minute quantities. Guillaume admits that the proper execution of commissural myelotomy is unquestionably more difficult than anterolateral cordotomy, but thinks that the operation is of value because the sensory defect and complications which follow are minimal. We have no personal experience with this procedure.

G. DORSAL CORDOTOMY

Browder and Gallagher (1946, 1948) and Pool (1946) have introduced this operation for the relief of painful phantom limbs. The former authors emphasize that in the patients they select for this operation the phantom is characterized by illusions of postural distortion, with a sensation as though the missing part were flexed in a cramped position or compressed in a vise. They find that this type comprises all 10 of the patients whom they saw with long-persisting phantom pain. In 38 others with complaints of burning, tingling, coldness, numbness, fulness, or electric shocks in the phantom extremity, the condition was transitory.

For relief of pain in the ghost of an upper limb, they advocated sectioning the lateral two-thirds of the ipsilateral dorsal column at the level of the second cervical segment, and for pain in a phantom lower limb they cut all of the fibres of the dorsal column at the midthoracic level. In order to identify the dorsal sulci they drop some blood or neutral methylene blue on the cord; the red cells or dye collect in the sulci and make them stand out, improving the precision of the incision. The cut can be made most accurately with the broken triangular point of a knife blade protruding from the jaw of a haemostat, inserting it at the midline. A depth of 6 mm.

at C2 and 4.5 mm. at T2* is sufficient to reach the depths of the posterior column and the cutting edge of the blade can be used to sever the tract out to its lateral margin at the point of emergence of the posterior rootlets.

In our single experience with this procedure, described on page 407, the painful phantom sensations which persisted after an apparently adequate anterolateral cordotomy were in no way altered. Pool has recently written us that he has lost all enthusiasm for this operation.

*These represent average measurements from four spinal cords, with extreme variations of less than 1 mm. above and below this figure.

CHAPTER IX

INTERRUPTION OF PAIN PATHWAYS IN SPINAL CORD, MEDULLA, AND MESENCEPHALON (CONTINUED): OPERATIVE RESULTS AND COMPLICATIONS*

MOUNTING CRITICISM AND CONCERN over the uncertain results of cordotomy are justified in only a small proportion of cases. Better selection of cases, elimination of psychoneurotics and severe morphine addicts, better operative technique, and verification of the sensory level at operation will help avoid a large proportion of failures. It is also essential to realize that full analgesia must be produced to an adequate level, and that even a high-grade hypalgesia, which means the persistence of residual pain fibres, will generally not suffice.

A. METHODS OF TESTING FOR COMPLETE INTERRUPTION OF PAIN TRACT

Most surgeons are unaware of the fact that the loss of appreciation of single pricks or the continuous scratch of a needle point as a sharp or pointed sensation does not prove that analgesia is complete. Testing in this way may indicate only a high degree of hypalgesia. We also were unaware of this fact prior to 1946. In such instances after cordotomy stimulation with a pin or other painful agent may cause a disagreeable feeling not described as pain, but which the patient can distinguish from a normally painless stimulus. At times a disagreeable or painful quality may appear only after multiple rapid pricks with a sharp point (five to 10 rapidly repeated pricks of the pin over a centimeter square of skin). In such patients pain, which may or may not be similar to that present preoperatively, may recur after operation.

We were at first uncertain whether or not repetition of the anterolateral cordotomy would eliminate either the spontaneous complaint of pain or the discomfort on stimulation. We considered the possibility that other pathways in the cord outside the contralateral anterolateral quadrant might

*A considerable part of this section on results and complications following cordotomy was reported at the meeting of the Society of British Neurological Surgeons in Manchester on May 19, 1950, and published in *Brain* (White, Sweet, Hawkins, and Nilges, 1950). We wish to thank the editor of this journal for his kind permission to reproduce this material, which has been revised and extensively enlarged

transmit such stimuli. One such patient, for example, stated that a pin-point or a hot or an iced tube caused an electric shock or a burning, peculiar feeling coming on at once at the site of stimulus. However, the repetition of the thoracic cordotomy two segments higher was followed by elimination of her spontaneous pain and absence of the discomfort on objective testing. In other patients who complain of recurrent pain despite an adequate upper level of analgesia, thorough examination may reveal residual sensory islands in which pinprick or continuous pin scratch is sharp or unpleasant. In one such patient the only area of skin in which such pain could be elicited was limited to about 10 sq. cm., yet repetition of the cordotomy was followed by relief of all pain and analgesia in that zone as well. It is easy on this basis to understand how apparent complete analgesia may occasionally fail to relieve pain in a phantom limb, since small numbers of fibres which formerly supplied the amputated portion of the limb may still exist in the scar and have a few intact spinal connections with the thalamus. Banzet (1927) noted in his 30 cases that the five whose pain was not relieved had no analgesia in the painful area.

It is apparent that exhaustive testing is required to establish the adequacy of the denervation. Some astute patients learn to distinguish the point from the head of the pin in an analgesic zone merely by the greater area touched by the head of the pin. Accordingly, in order to avoid confusion, we test by comparing the response to a stimulus consisting of either (1) a fingertip alone, or (2) that plus the point of a pin projecting beyond the fingertip. These two stimuli should be indistinguishable in an ef-

TABLE II

*EFFECT OF ANTEROLATERAL CORDOTOMY ON PAIN IN 210 PATIENTS**

	No. Ops	%
A. *Early results following 241 operations (up to one month postoperatively):*		
Analgesia and complete relief of original pain:	196	81
Partial return of pain (insufficient to require narcotics):	23	10
Failure to relieve pain:	22	9
B. *Later results of 100 of these operations in patients who had early complete relief (two months or more postoperatively).*		
Effective relief, or no medication required (average 15 mos).	63	63
Partial relief (average 7 mos.):	18	18
Failure (average 7 mos.)·	19	19
C *Late results of unilateral cordotomy in 20 patients submitted to detailed follow-up studies (five months to ten years after operation)·*		
Effective relief, or no medication required (average 46 mos.)	15	75
Partial relief (average 40 mos.):	2	10
Failure (average 63 mos.):	3	15

*These statistics apply to relief of the original pain For data on subsequent appearance of pain on opposite side after unilateral cordotomy, see p 242

CHAPTER IX

INTERRUPTION OF PAIN PATHWAYS IN SPINAL CORD, MEDULLA, AND MESENCEPHALON (CONTINUED): OPERATIVE RESULTS AND COMPLICATIONS*

MOUNTING CRITICISM AND CONCERN over the uncertain results of cordotomy are justified in only a small proportion of cases. Better selection of cases, elimination of psychoneurotics and severe morphine addicts, better operative technique, and verification of the sensory level at operation will help avoid a large proportion of failures. It is also essential to realize that full analgesia must be produced to an adequate level, and that even a high-grade hypalgesia, which means the persistence of residual pain fibres, will generally not suffice.

A. METHODS OF TESTING FOR COMPLETE INTERRUPTION OF PAIN TRACT

Most surgeons are unaware of the fact that the loss of appreciation of single pricks or the continuous scratch of a needle point as a sharp or pointed sensation does not prove that analgesia is complete. Testing in this way may indicate only a high degree of hypalgesia. We also were unaware of this fact prior to 1946. In such instances after cordotomy stimulation with a pin or other painful agent may cause a disagreeable feeling not described as pain, but which the patient can distinguish from a normally painless stimulus. At times a disagreeable or painful quality may appear only after multiple rapid pricks with a sharp point (five to 10 rapidly repeated pricks of the pin over a centimeter square of skin). In such patients pain, which may or may not be similar to that present preoperatively, may recur after operation.

We were at first uncertain whether or not repetition of the anterolateral cordotomy would eliminate either the spontaneous complaint of pain or the discomfort on stimulation. We considered the possibility that other pathways in the cord outside the contralateral anterolateral quadrant might

*A considerable part of this section on results and complications following cordotomy was reported at the meeting of the Society of British Neurological Surgeons in Manchester on May 19, 1950, and published in *Brain* (White, Sweet, Hawkins, and Nilges, 1950). We wish to thank the editor of this journal for his kind permission to reproduce this material, which has been revised and extensively enlarged

plexuses on both sides. Most frequently, however, unilateral cordotomy gives complete and lasting relief of pain initially unilateral. Conversely, in three individuals in whom the pain was bilateral from the beginning very satisfactory relief has followed unilateral incision. Two of these patients suffered from tabetic crises and one from malignant disease. The latter was completely freed of her original bilateral anorectal pain and all other pain until her abrupt demise seven months after cordotomy. Of the patients with tabetic crises, one continues so nearly free of his gastric crises after four years that he has lost no time from work and gained 50 pounds to reach a normal weight; the other, with lightning pains in both the lower limbs, remains greatly relieved at four years. For these reasons and because a bilateral cordotomy at one stage leads to a higher incidence of bladder complications than when this operation is performed in two stages (see below), we usually recommend a trial of unilateral cordotomy when pain is not severe on both sides.

Prolonged follow-up of the early successful cases is of particular importance, as there is always the possibility that the initial satisfactory level of complete analgesia may recede many segments, or be replaced in a patchy manner or throughout by a variable degree of hypalgesia. As an example, a patient who was effectively relieved of pain in the stump of an amputated thigh for over a year had a recurrence following a late drop of the sensory level. After intervals of over two months, 63 per cent of 100 operations continued to give complete relief on the denervated side, 18 per cent partial improvement, and 19 per cent no benefit (Table IIB).

In Grant's (1943) large carefully studied series of 56 bilateral and 70 unilateral cordotomies, 64 per cent of the patients were completely relieved, 15 per cent were 75 per cent relieved, 7 per cent still had half of their pain, 4 per cent were not relieved, and 10 per cent died. These favourable results ensued despite the fact that 80 per cent of the patients had malignant tumours. Even in the smaller series of many surgeons reporting earlier, the results were encouraging. Stebbing (1929) found a measure of relief in all of 15 cases which justified the operation. Pain returned in five of Babtchine's (1929) 22 cases, but in three of these another cordotomy was done which stopped the pain. In Sasaki's (1938) 19 cases with painful obliterative arterial disease in a limb, relief was obtained in all but one patient with minimal hypalgesia; a second cordotomy 10 months later stopped his pain. Several of these patients obtained relief even though only hypalgesia, rather than analgesia, was attained. Similar fortunate experiences are on record: in Frazier's (1920) Case 3 and Frazier and Spiller's (1923) Case 6 (both with carcinoma in the torso) and in Horrax' (1929) Cases 2 and 7 with tabetic pains. Peet (1926) and Petit-Dutaillis (1937) have also noted this in some of their cases. In Banzet's (1927) Case 21 the

fectively cordotomized area. If they can be differentiated and the stimulus with the pin is more disagreeable, our current impression is that a deeper cordotomy will often stop the pain. This has been the outcome in at least four such cases.

B. RESULTS OF ANTEROLATERAL CORDOTOMY

Table IIA shows that 196 operations or 81 per cent of the total gave complete relief of the original pain up to the time of the patient's discharge from the hospital. Partial return of pain, but insufficient to require further administration of narcotics, occurred in 10 per cent, while 9 per cent resulted in less satisfactory or no relief. Of the 157 operations first performed on one side only, 89 were in patients who had malignant disease of the torso. In this group there was an early appearance (within two months) of pain on the opposite side in 31, or 35 per cent. In an additional eight of 20 individuals in this latter group who were followed for over two months, pain later appeared on the opposite side. In 39 sufferers from malignant disease, or 44 per cent of the total observed, unilateral cordotomy was therefore insufficient to provide lasting relief. This sequel was much less frequent in nonmalignant conditions of the torso, where it appeared only four times in 36 patients, 28 of whom were followed for two or three months. Cross-over of pain never occurred in patients with disease confined to a single extremity.

The pain of advanced carcinoma may be so severe on one side that lesser contralateral discomfort is masked. Nevertheless, the patient may become aware of severe pain on the opposite side just as soon as the predominant complaint has been eliminated. This is also true of pain in other varieties of visceral disease arising from midline organs such as the heart and pancreas. Just as soon as the pain on the predominant side has been relieved by sympathectomy or splanchnicectomy it is likely to be noticed on the opposite side, because these organs have bilateral innervation. Furthermore, as noted in Table VI (p. 264) we find that reference of pain to the normal side may occur when the gut on the analgesic side is distended. This erroneous reference of pain to an area other than that stimulated may occur also with a variety of superficial and deep noxa discussed under the heading of allachaesthesia on p. 256. In view of these facts it is not surprising that transference of pain to the side originally uninvolved occurs. This is most likely to happen in carcinoma of the uterus, rectum, bladder, or prostate,* where lymphatic spread so often involves the lumbosacral

*One patient in the advanced stage of carcinoma of the prostate with bony pelvic metastases had complained of only unilateral pain The day after its operative relief he complained that it had shifted in full severity to the opposite side, necessitating a secondary contralateral tractotomy a week later

from advanced malignant disease. These included exsanguination from erosion of large blood vessels by tumour, uraemia from ureteral obstruction, and generalized cachexia. Many earlier reports indicate a somewhat higher percentage of deaths, as follows: Banzet (1927), 25 per cent of 16 cases with cancer, 14 per cent of 14 cases without cancer; Frazier and Spiller (1923), 13 per cent of eight cases; Grant (1930), 14 per cent of 51

TABLE III

COMPLICATIONS FOLLOWING CORDOTOMY

A. Complications Persisting to Time of Discharge in 210 Patients

	Operative Deaths	*Bladder*	*Bowel*	*Incisional Radicular Pain*	*Motor Weakness*	*Case Total*
Unilateral*:	3	5%	2%	2%	4%	126
Bilateral, 1-stage.	5	29%	5%	2%	8%	65
Bilateral, 2-stage:	1	16%	10%	0	10%	19
Total:	9	13%	4%	1%	5%	210

*10 of these, with incomplete analgesia and continued pain, were submitted to secondary cordotomy without any complications.

B. Comparison of Complications Following Unilateral Thoracic and High Cervical Cordotomy

	Operative Deaths	*Bladder*	*Bowel*	*Incisional Radicular Pain*	*Motor Weakness*	*Case Total*
Thoracic.	0	2%	2%	1%	4%	92
Cervical:	3	12%	3%	3%	3%	34

cases; Olivecrona (1947B), 13 per cent of 55 cases. Increasing use of the procedure for benign disorders and better methods of postoperative care are perhaps responsible for the decline in mortality. Sjöqvist (1949), for example, whose series of 58 includes only 25 per cent with malignant tumours, had only a 4 per cent mortality—essentially the same as in Sasaki's (1938) 19 cases of painful obliterative arterial disease. It is evident from Table IIIB that the incidence of deaths is somewhat greater after high cervical tractotomies than after those carried out in the upper thoracic portion of the spinal cord.

2. Retention of Urine

The most generally feared sequelae of cordotomy are disturbance in control of the bladder and muscular weakness. The postoperative incidence of these complications and others which are less commonly recognized are summarized in Table III. Persistent disturbances of micturition consist of an atonic bladder with retention. Much less frequently there has been relaxation of the vesical sphincter and annoying dribbling. During the first week after operation retention is so common that we routinely insert a Foley catheter in the operating room. Tidal drainage may be used and is essential

itching of bilateral kraurosis vulvae was stopped permanently by a bilateral cordotomy which yielded analgesia to T8 on one side, but only slight hypalgesia over the lower leg and foot on the other side.

Sjoqvist (1949) presents a less encouraging picture after careful study of a large series. In particular, his patients with non-fatal diseases followed for years tended to be unhappy. Of 25 such instances of painful affections of the hip-joint, chiefly arthritis deformans, the result was excellent in only two cases, "fair" in nine, and "the remaining patients were discontented," usually because of increased difficulty in walking or new pain differing from the preoperative complaint. Neither of these latter two symptoms has been a significant problem in our series with long survival studies which follows, but we have operated on very few arthritics. Our one patient, however, with lasting disturbance of gait had arthritis of the hip joint. If the cordotomy is to be successful the pain ordinarily stops immediately after the incision into the cord. Nesbit (1947), however, reports two patients whose severe constant pain in the bladder from a refractory interstitial cystitis persisted two or three weeks after bilateral cordotomy, then ceased and has remained absent for years.

Special examinations were obtained in 20 of our patients after postoperative periods ranging from five months to 10 years. The observations in 14 were made over two years postoperatively. These include all of our patients whose return for such study we were able to arrange and represent no other special selection. Many of these late survivors were amputees who formerly suffered from painful limb phantoms or major neuralgia in their stumps. Fifteen, or 75 per cent, maintained a satisfactory degree of relief. There were two who required small amounts of medication and three were failures. These are summarized in Table IIC. The causes of early and late failures will be analyzed below. It is possible that this series is unduly weighted with our successes. We know of several other cases in which the operation failed to give permanent relief, but we were unable to persuade the patients to return for examination.

C. COMPLICATIONS OF ANTEROLATERAL CORDOTOMY

1. Mortality

The mortality directly due to the operation amounted to 4 per cent in this series of 210 patients, 168 of whom were operated upon in the advanced stages of malignant disease (Table III). Of these nine deaths attributed to the operation, two were caused by immediate circulatory and respiratory failure, four by atelectasis and pneumonia, and one each by pulmonary embolism, cerebral contusion following a fall, and pyelonephritis secondary to prolonged catheterization. Thirteen other deaths occurred in the hospital

function was regained in one to 20 days by all eight tabetics with gastric crises on whom Hyndman and Jarvis (1940) made bilateral cuts at the T2 and T3 segments. Isolated instances of long-lasting retention after bilateral cordotomy are recorded, however, by Petit-Dutaillis (1937), longer than 30 days in three out of 10 patients; by Banzet (1927), one case lasting two and a half months; by Sjöqvist (1949), one case lasting a year. In two of Babtchine's bilateral cases retention for the first month or two was followed by incontinence; in the four of Banzet's 30 cases in which incontinence occurred there were pyramidal signs in each—slight in one, marked in three. On our service after bilateral cordotomy performed at one stage the incidence of this complication rose to 29 per cent, but when both anterolateral columns had been transected in two stages a week or more apart this was reduced to 16 per cent. These statistics refer to the proportion of patients who still required catheterization at the time of discharge from the hospital.

Unfortunately we have had no patients with bilateral cordotomies for prolonged observation of bladder function who have maintained total analgesia of the sacral segments but were free from pre-existent damage to the spinal cord and in good general condition. In general we agree with the report of Nathan and Smith (1951), who have followed a large series of anterolateral cordotomies at the National Hospital in Queen Square, London. They concluded that the pathways of bladder sensibility lie in the dorsolateral portion of the anterior quadrants in close relation to the pain fibres from the sacral region. In the presence of bilateral analgesia sensation of bladder filling and the urge to urinate are at first seriously impaired. The degree of impairment is somewhat variable, as in some individuals the desire to pass water and awareness of urination may be lost, at least for the first week or two. In others there are "substitute" sensations, such as a non-specific sense of abdominal distension when the bladder fills and other signs such as are seen in paraplegics. As time goes by most patients regain* "the sensation that micturition is impending, that it is progressing, and that it has ceased. These sensations are doubtless due to impulses arising in the urethral mucosa and in the sphincter urethrae membranaceae and the large group of perineal muscles that act synergically with the sphincter. Such impulses doubtless travel via the posterior columns." Even though the normal sensation of bladder filling is no longer present, the cystometrogram is usually normal or responds in a somewhat hyperactive fashion to the stretch reflex of smooth muscle. In this way even the hyposensitive bladder is effectively emptied if there is no concomitant injury to the lower sacral nerves or mechanical obstruction to its outflow.

---

*Nathan, P.W. and Smith, M.C.: The centripetal pathway from the bladder and urethra within the spinal cord. *J. Neurol Neurosurg Psychiat.*, London, 1951, *14* 262-280.

if spontaneous voiding fails to start within a week. However, a cystometrogram made at this time, when the patient is up, usually shows active reflex contractions with sensation of fulness at volumes over 200 cc. The catheter is then removed, but reinserted on one or more occasions after the return of spontaneous micturition to determine the presence of residual urine. Catheterization should be continued once or twice a day if this remains excessive, or the inlying catheter should be replaced for a further period if there is any serious retention. Only rarely has it been necessary to resort to protracted tidal drainage for bladder retraining, but so much can be accomplished by this that prolonged impairment of voluntary control is now a rare problem.

Following a unilateral upper thoracic tractotomy only 2 per cent of our patients have continued to have difficulty to an extent that required catheterization beyond the time of discharge from the hospital. With afferent innervation preserved on one side, normal sensation of the presence of urine in the bladder and its passage was usually maintained. In the individuals who had prolonged retention there was nearly always some pre-existent mechanical obstruction or neurogenic impairment in the emptying of the bladder secondary to pelvic or spinal disease. A high incidence of brief urinary retention early after the one-sided operation has been repeatedly mentioned by others: Babtchine (1929), 70 per cent of 22 cases; Banzet (1927), 76 per cent of 30 cases. Grant (1930), however, also pointed out that other contributory factors usually account for any prolonged disturbance in urinary control. In six of his 55 unilateral cordotomies with persistent retention, three were in patients with carcinoma of the prostate and three had had a previous subarachnoid alcohol injection. Following unilateral high cervical cordotomy in our experience, the incidence of bladder complications appears to be significantly raised (12 per cent—Table IIIB). We have not found Prostigmin or other cholinergic drugs of much value. A few patients, particularly elderly males with slight degrees of prostatic enlargement and others with involvement of the sacral nerves, have required transurethral excision of tissue at the bladder neck. In the special group of 20 patients who were reviewed between five months and 10 years after unilateral cordotomy, all had adequate control of urination.

Others have emphasized the increase in urinary complications when the incisions are deep and bilateral. Although 13 of Stebbing's (1929) 14 patients with the cut on both sides and in the same segment were voiding normally in one week, these incisions were only 3 mm. deep. With bilateral incisions Kahn and Peet (1948) found that the greater their depth the greater the number of permanent bladder complications. But even the generous slashes of Foerster and Gagel (1932) never produced permanent urinary retention unless previous disease was a contributory factor. Bladder

performing these operations under local anaesthesia, for such paralyses have usually cleared within a day or two. Many others have mentioned the disconcerting occurrence of transitory paralyses: Frazier (1920), Case 6; Frazier and Spiller (1923), Case 4; Peet (1926), 5 of 17 bilateral cordotomies; Babtchine (1929), five of 17 unilateral cordotomies; Sasaki (1938), two of 19 unilateral operations; Falconer and Lindsay (1946), one of two high cervical cordotomies. However, in many other series besides ours lasting severe weakness rarely occurred. Sicard and Robineau (1925) stated that there was no real weakness in their 11 cases. Although six of Petit-Dutaillis's 25 thoracic cordotomies had some weakness in the legs, walking and standing were unimpaired; and only one of Banzet's 30 cases had severe weakness, which was beginning to recover on the single side affected 17 days after a bilateral operation. Of Hyndman and Jarvis's eight tabetics operated on bilaterally, seven walked alone on leaving the hospital and the eighth was prevented from doing so only by generalized weakness following withdrawal of narcotics. One-stage bilateral cordotomies have, however, led to more difficulties. Each of the three operations Babtchine (1936) did in this fashion caused a paralysis of both legs and of the pelvic organs "which vanished only slowly." In one of these three operations both incisions were in the same segment. Stebbing's 16 bilateral cordotomies at the same segment caused paraplegia for a few days in two patients and paraparesis for two to three weeks in five others. In Frazier and Spiller's Case 3 the postoperative severe paraparesis was correlated with considerable bilateral degeneration in the crossed pyramidal tracts.

Hypotonia ipsilateral to the incision has been remarked upon by Babtchine and was considered to be a cerebellar sign by Banzet and by Petit-Dutaillis. Any abnormal amplitude of movement at the joints is never a source of disability.

On the rare occasions when severe degrees of paresis persist, it is our opinion that this may be caused by injury to the blood supply of the pyramidal tract. Suh and Alexander (1939) have shown that this is supplied by branches from the anterior spinal artery which pass through the base of the anterolateral quadrant. If one of these is injured oedema or necrosis may develop in a portion of the lateral corticospinal tract. Observations made in the course of deliberate section of this tract, as practised by Putnam (1940) and Ebin (1949) in their operations for Parkinson's disease, have demonstrated that interruption must be extensive to produce serious weakness. Figures 77A and B are photomicrographs of the spinal cord in two patients who died from spreading carcinoma following upper thoracic cordotomy. While both incisions appear to have been made too far dorsally, there was no noticeable weakness of the leg from partial transection of the

3. Faecal Incontinence

Temporary inability to control the anal sphincter with faecal incontinence was observed much less frequently. Prolonged relaxation or inability to distinguish between gas and faeces led to soiling of the clothes at times in eight patients, three of whom had been previously subjected to subarachnoid injection of alcohol. Banzet mentions "slight faecal incontinence" in two of his 30 cases, Sasaki (1938) "transitory faecal incontinence" in two of 19 cases. Babtchine (1929) reported paralysis of the gut in three cases lasting only two to five days after repeated bilateral cordotomy, and Foerster and Gagel have seen a temporary paralytic ileus after bilateral cordotomy, which was treated effectively by a rectal tube or by injections of pituitrin. We have had the same experience and are on the alert in the postoperative period for abdominal distension from this cause. Its infrequency tends to make one forget about it; Grant saw it only four times in 29 bilateral operations and in one out of 22 unilateral ones, but it should not be ignored, as witness the death due to paralytic ileus in one of Stebbing's cases.

4. Leg Weakness

Obvious weakness of the leg on the side of the cordotomy was a cause of complaint after 4 per cent of our unilateral operations, and twice as often after bilateral tractotomy. It was fortunately not a problem in any of the 19 individuals who had the operation performed for painful leg phantoms or stump neuralgia, and it continued to be a source of complaint in only a single patient examined after five months. This man, with degenerative arthritis of the hip, required support of a cane in walking but had so much disease in the hip on the side of the tractotomy that it was difficult to estimate the degree of residual weakness. However, if strength of individual muscles is measured quantitatively and compared on the two sides after unilateral operations, a definite weakness will nearly always be found during the first few weeks on the side of the tractotomy.* In one recent patient an early organic weakness led to a severe functional paralysis, but this cleared promptly as soon as it was recognized and psychotherapeutic measures instituted.

Paralysis on the ipsilateral side can come on immediately after the initial or any subsequent cut into the cord. Its occurrence should be looked for when sensation is tested so that the surgeon will not be tempted to extend his incision. The possibility of spotting the onset of paralysis in the course of deepening the anterolateral incision is another argument in favour of

*We are indebted to Dr. Arthur L. Watkins of the Department of Physical Medicine, Massachusetts General Hospital, for his tests in these cases.

performing these operations under local anaesthesia, for such paralyses have usually cleared within a day or two. Many others have mentioned the disconcerting occurrence of transitory paralyses: Frazier (1920), Case 6; Frazier and Spiller (1923), Case 4; Peet (1926), 5 of 17 bilateral cordotomies; Babtchine (1929), five of 17 unilateral cordotomies; Sasaki (1938), two of 19 unilateral operations; Falconer and Lindsay (1946), one of two high cervical cordotomies. However, in many other series besides ours lasting severe weakness rarely occurred. Sicard and Robineau (1925) stated that there was no real weakness in their 11 cases. Although six of Petit-Dutaillis's 25 thoracic cordotomies had some weakness in the legs, walking and standing were unimpaired; and only one of Banzet's 30 cases had severe weakness, which was beginning to recover on the single side affected 17 days after a bilateral operation. Of Hyndman and Jarvis's eight tabetics operated on bilaterally, seven walked alone on leaving the hospital and the eighth was prevented from doing so only by generalized weakness following withdrawal of narcotics. One-stage bilateral cordotomies have, however, led to more difficulties. Each of the three operations Babtchine (1936) did in this fashion caused a paralysis of both legs and of the pelvic organs "which vanished only slowly." In one of these three operations both incisions were in the same segment. Stebbing's 16 bilateral cordotomies at the same segment caused paraplegia for a few days in two patients and paraparesis for two to three weeks in five others. In Frazier and Spiller's Case 3 the postoperative severe paraparesis was correlated with considerable bilateral degeneration in the crossed pyramidal tracts.

Hypotonia ipsilateral to the incision has been remarked upon by Babtchine and was considered to be a cerebellar sign by Banzet and by Petit-Dutaillis. Any abnormal amplitude of movement at the joints is never a source of disability.

On the rare occasions when severe degrees of paresis persist, it is our opinion that this may be caused by injury to the blood supply of the pyramidal tract. Suh and Alexander (1939) have shown that this is supplied by branches from the anterior spinal artery which pass through the base of the anterolateral quadrant. If one of these is injured oedema or necrosis may develop in a portion of the lateral corticospinal tract. Observations made in the course of deliberate section of this tract, as practised by Putnam (1940) and Ebin (1949) in their operations for Parkinson's disease, have demonstrated that interruption must be extensive to produce serious weakness. Figures 77A and B are photomicrographs of the spinal cord in two patients who died from spreading carcinoma following upper thoracic cordotomy. While both incisions appear to have been made too far dorsally, there was no noticeable weakness of the leg from partial transection of the



Fig. 77. Photomicrographs of two incomplete anterolateral cordotomies.

A (*upper*). George B., MGH U-665888BM. After incision in left side of cord at another hospital this man had high-grade hypalgesia to costal margin but no complete analgesia. The pain in his right thigh, caused by metastases of gastric carcinoma to the femur and ninth thoracic vertebra, was not relieved. There was no loss of bladder control nor any motor weakness. He died two months later.

B (*lower*). Lillian H., MGH U-23976. Cordotomy in Patient 8, Table XLII. This woman with carcinoma of cervix died of uraemia 18 days after bilateral cordotomy. Section cut at level of lower incision. Although this was placed somewhat too far posteriorly, the patient

pyramidal tract. Frazier (1920) and Banzet (1927) have each reported postmortem evidence of an incision involving the pyramidal tract without clinical evidence of weakness. We have recently observed a patient (Mary L., MGH U-630982) develop complete paraplegia which did not appear until three days after an uneventful bilateral transection of both anterolateral quadrants for pelvic carcinoma. This patient was able to move her legs freely for 48 hours and then suffered a rapid paralysis with sparing of touch, position, vibratory sensation, and graphaesthesia. The most logical explanation for this unusual complication is a delayed spontaneous thrombosis of the anterior spinal artery.

5. Respiratory Paralysis

Another rare form of weakness, but a major disaster when it occurs, is respiratory paralysis consequent upon upper cervical cordotomy. One of Penfield's (1943) patients stopped talking in the midst of a sentence while his wound was being closed and died promptly after a unilateral incision at C2. Autopsy did not help explain the death. Hyndman (1948) after a similar operation had to keep his patient in a respirator during the remaining three months of her life. Stookey (1943) has seen respiratory deaths after upper cervical cordotomies only when they were bilateral. The possibility of serious respiratory impairment must be kept particularly in mind if a cervical cordotomy is to be done in an individual with previous unilateral paralysis of the diaphragm, as may be the case in a painful tumour of the thoracic outlet, because respiration may be further impaired by incising the opposite side of the cord.

6. Hypotension

An occasional temporary complication is the low blood pressure which may follow bilateral cordotomy. On some six occasions we have seen the blood pressure fall to shock level (60 to 70 mm. systolic) at the time the second anterior quadrant was cut and remain below 90 or 100, usually for a period of three days to a week. This may occur when the incision is made on the second side in either a one- or two-stage cordotomy. It has been most severe and persistent when the operation has been performed at a high cervical level. In one woman, in whom the second cordotomy was made at the second cervical level, the pressure remained below 80 for over a week and continued for several weeks to drop to a syncopal level when she stood up. This patient required medication with Neo-Synephrine for the first few days and then pressure bandages on the legs and a tight abdominal binder for several weeks before full vasomotor compensation took place. Despite the shock level of blood pressure these patients remain normally

alert and show no signs of vasomotor collapse. The situation resembles that seen in high spinal anaesthesia with paralysis of vasoconstrictor tone and peripheral dilatation.

Experience has shown that hypotension after cordotomy is usually harmless and will soon correct itself. However, in one patient with a blood pressure on admission of 124/60 an extensive bilateral one-stage upper thoracic cordotomy at segments T1 and T4 dropped the pressure to 85-95/55-60, where it was remaining without inconvenience to the patient when she was discharged 17 days later. On the first, second, and third postoperative days Neo-Synephrine hydrochloride 1 mg. had been given subcutaneously nearly every hour; this provoked a transitory rise in blood pressure, followed by a fall to 70-90 mm. systolic each time. Ephredrine sulphate 25 mg. subcutaneously four times a day during the second week postoperatively had no effect on the blood pressure. Figure 68A shows the dorsal extent of a lesion which must have wiped out the area all around the intermediolateral cell column in the neighbourhood of which the vasomotor fibres are presumed to lie. The lesion on the other side of the cord at the T4 segment was even larger, extending slightly beyond the midline. Since this patient's neoplasm had destroyed much of one femur, she did not try to walk again, but in order to stand upright she probably would have required tight bandaging of her legs for a while, as was the case for a time after the last operation in another of our patients (John R., N.E.C.H. #43-917), who had had three upper thoracic cordotomies. The orthostatic hypotension observed in our patients has never persisted, as it so often does in such an annoying way after extensive thoracolumbar sympathectomy for hypertension.

Exceptions to this statement have been reported by others. Johnson, Roth, and Craig (1952) describe a 45-year-old woman submitted to bilateral anterolateral cordotomy in two stages at the first and second thoracic level for persistent pain following multiple ineffective operations for lumbar disc disease. After the second cordotomy the patient had bilateral impairment of sweating over large areas of the body and such extreme orthostatic hypotension that she would faint on sitting up. With an abdominal constrictive binder and leg bandaging she improved progressively, although orthostatic changes in blood pressure were still severe at six months unless pressure bandages were worn. Hyndman (1948) also alluded briefly to two patients who maintained a permanent severe orthostatic hypotension after bilateral upper thoracic cordotomy. He and Wolkin (1943) made careful vascular studies before and after bilateral upper thoracic or lower cervical cordotomy in four patients with severe essential hypertension. A normotensive status early after operation was followed by gradual return to hypertensive levels within six to 20 months. Sjöqvist (1949) noted a marked

temporary drop in blood pressure in 25 of his 58 cases; operation was unilateral in 17 and bilateral in eight patients. Pronounced postural hypotension lasting for months followed two of the unilateral and three of the bilateral operations; this persisted for more than two years in one person.

7. Reflex Changes

Changes in reflexes observed five months or more after operation were slight. Ten of the 20 individuals tested had demonstrable evidence of mild neurological abnormality: a reduction in abdominal and cremasteric reflexes, a slight but definite increase in the deep tendon jerks, or a positive Babinski response.

8. Bedsores

In earlier decades decubitus ulcers occurred after cordotomies in 11 of Banzet's 30 cases and in three of Sasaki's 19 patients. With better nursing and nutritional attention postoperatively we no longer see these.

9. Radicular Pain

Other postoperative complications consist of radicular pain, reduced sexual function, and various forms of dysaesthesia and allachaesthesia. After cordotomy it is common for the patient to complain of more or less disagreeable sensations radiating to one or both sides along the course of the spinal nerves at the segmental level of the incision. This usually disappears in the course of a few weeks, but one patient examined claimed that she was disturbed by the sensation for three years before it finally vanished. Leighton (1921) first suggested that posterior rhizotomy be done to eliminate these pains, but Banzet observed these for only three to eight days after operation and hence thought they did not constitute an indication for posterior rhizotomy. Babtchine (1929) stated that the girdle pains rarely lasted longer than three weeks in his 22 patients, although in four of them the previously painful zone remained hyperaesthetic for many months. Stebbing observed persistent girdle pain at six months in one of his 17 cases, a man who had had a painful amputation stump. The only one of Petit-Dutaillis's 25 patients who had such pain persist had a "neuropathic personality." We agree with Stookey (1943), who wrote, "I have not been able to convince myself that this occasional annoying pain is avoided by cutting the dorsal root." In fact, avoidance of trauma in handling the posterior roots appears to us the best way to reduce postoperative radicular pain. When we do the intradural part of the operation with the patient awake, he promptly notifies us as soon as undue tension is placed on these rootlets. This effective method of avoiding trauma at this stage of the operation leads

to less postoperative pain. Hyndman and Wolkin (1943) have provided another type of evidence bearing on this point. They find that girdle pain of varying degree develops in about half of their cordotomized patients, but that this is limited to a narrow band at the zone of transition from analgesia to algesia—viz., in the zone of hypalgesia. This strip may be quite *distant from sensory roots at the level of incision and pain may follow either* rhizotomy or cordotomy. Indeed, in two of their patients who had bilateral posterior rhizotomy from T1 to T5 and T1 to T4 respectively along with cordotomies, this type of pain was present at both the upper and lower levels of thoracic anaesthesia. It was so severe that sympathectomies were subsequently tried—fruitlessly—for relief. Although Hyndman and Wolkin are describing another source of pain than that from trauma to intact posterior roots incidental to cordotomy, their experience adds weight to arguments against supplementary rhizotomy.

10. Loss of Sexual Function

Masculine complaints on the score of reduced sexual potency or gratification range all the way from complete impotence to the statement that the voluptuous sensation of intercourse is lost, even though erection and ejaculation may still take place (Kahn and Peet, 1948). Sjöqvist agrees that the sense of voluptuousness is lost after section of the spinothalamic tract, and Foerster and Gagel probably meant essentially the same thing when they said that erection and ejaculation were normal but that libido and orgasm were stopped. Oldberg (1932) and Stookey (1943) have even stated that impotence always follows cordotomy—that the patient, although able to have erections, cannot ejaculate. Olivecrona (1947B) stated that "some disturbance of potency may occur after unilateral section." In contrast, one of our patients, aged 66, boasted that he enjoyed normal intercourse the night he left the hospital after a successful unilateral cordotomy. Any severe operation may reduce sexual activity, but in general in our patients after unilateral cordotomy for pain with nonfatal disease there has been a gradual return of function over a period of weeks to years. Sasaki (1938) also mentioned that in two of his males aged 24 and 38 there was "no disturbance of sexual drive" after one-sided cordotomy.

The bilateral operation, on the other hand, is almost certain to abolish erection and orgasm in the male, according to Hyndman and Wolkin. Most of these patients had tabetic gastric crises so that sexual function was probably partially impaired or at least more vulnerable preoperatively. Olivecrona also states that complete impotence is to be expected after all bilateral cordotomies. This was true even for one of Sasaki's patients with benign disease, but in favourable circumstances this deficit may not be permanent.

Nesbit (1947), for example, mentions a male who had normal sexual desire and function after the bilateral operation which relieved pain of a refractory interstitial cystitis, and produced analgesia to T9 and T10 segments respectively maintained two years after operation.

Women also may notice some reduction or absence of genital activity and pleasurable sensation during intercourse, even after unilateral cordotomy. In our group there were only three vigorous married women to question. Two had essentially normal sexual satisfaction and one of these became pregnant. *Tactile stimulation of the vulva and stretching of the perineal musculature, giving rise to impulses transmitted via the posterior columns, may explain partial preservation of erotic sensation.* A third girl, however, complained of absence of all erotic sensation in the genital region, despite unimpaired libido. This result coincides with the opinion of Hyndman and Wolkin that when analgesia of the perineum and vagina is bilateral orgasm will be lost.

11. Dysaesthesia and Paraesthesia

Eight patients have complained of dysaesthesias in the hypalgesic or analgesic areas. These have consisted of a wide variety of subjective sensory disturbances: sensation of "pins and needles" (three cases), "electric shock-like pain" in leg (two cases), "rawness" over great trochanter (two cases), "burning" in foot (one case), and disagreeable "numbness" (one case). The latter complaint was difficult to evaluate, as this man was effectively relieved of his painful phantom leg, but deeply resented the fact that he could stick pins through his analgesic skin without normal sensation. The patient with residual burning sensation in her foot was a psychoneurotic in whom evaluation was difficult, but the others seemed to be relatively stable from an emotional standpoint.

In the course of the three years elapsed since these 210 patients submitted to anterolateral cordotomy were critically studied we have had one other patient who has complained intensely of disagreeable paraesthesia and have seen two other examples occurring in individuals operated upon by other surgeons. In each instance loss of pain sensation was not complete, although in one patient (Adeline R., see p. 335) the constant spontaneous dysaesthesias were referred widely to the arm and leg, which were analgesic except for part of the foot. These subjects experienced very unpleasant tingling, radiating sensations not unlike the phenomenon of "over response" seen with incomplete lesions of peripheral nerves or in the thalamic syndrome. While a more powerful prick or scratch had to be used to break through the elevated threshold of the hypalgesic zone, the sensation elicited was far more disagreeable than from comparable stimuli in normally in-

nervated cutaneous areas. Other complaints such as deep aching or shooting pains were a further cause of frequent discomfort. While this complication has not been stressed in the literature,* it can be just as annoying a complication as the "anaesthesia dolorosa" that occasionally follows retrogasserian neurectomy. We have fortunately seen it in a really troublesome degree only twice in our series of over 300 cordotomies. The statement that the analgesic area feels as though it were icy cold is a rare complaint which we have encountered only once. This occurred after a high cervical cordotomy for malignant disease in the chest, with a very gratifying analgesia to the shoulder level (Mahmed Z., MGH U-728614). Fortunately this complaint gradually subsided and the patient hardly noticed it at 19 months.

Sjöqvist is the only other observer whom we find to have noted the incidence of these complications in a large series of cases. In five of his 71 cordotomies on 58 patients there was a disagreeable hot or cold sensation in the analgesic or hypalgesic area, and in six instances there was burning pain. One of Falconer's patients (personal communication, 1948) after high cervical cordotomy for pain in a phantom upper limb began to complain of burning pain below the costal margin only after this previously analgesic area became hypalgesic, and stimuli here had a peculiarly unpleasant quality. Our patients with the worst dysaesthesias had high cervical incisions. A similar condition, although of greater severity and much higher frequency, is reported below in the section on transection of the spinothalamic tract in the midbrain (see p. 284).

One may note in passing that Sicard, Haguenau, and Wallich (1927) describe the symptom of "isothermognosia," the transformation of all perceptions in the cordotomized territory into a uniform sensation of warmth. They regard this not as a complication but as the accompaniment of a clinical cure and as proof of a correctly performed cordotomy. We have rarely noted this in our own successful cases.

12. Allachaesthesia

The reference of sensation from analgesic skin to other areas is a curious misinterpretation of the origin of sensory stimuli. As an example of this phenomenon, a woman with a shoulder disarticulation and a painful phantom of her arm, which seemed to be drawn up in a cramped position behind her back, had been relieved of all discomfort for six months following anterolateral cordotomy at the first cervical level. The phantom unfortunately reappeared because her level of analgesia fell, with the appearance of islands

*We have found a single case reported by Oldberg (1932) in which tabetic crises were relieved with analgesia reaching to the sixth thoracic segments on both sides only to have the result marred by new aching pains in both groins

of disagreeable sensation over the trunk and leg. Rapid repetitive pricking with a pin in these areas was then perceived as peculiarly disagreeable, rather than normally painful, but this sensation was referred to her shoulder stump and phantom arm. Another woman with multiple bony metastases from carcinoma of the breast, which caused left lower abdominal and leg pain, was effectively relieved of her discomfort. Her analgesic level after cordotomy reached the mid-thorax, but she was able to identify repeated pinpricks below this level by a disagreeable sensation referred to her axilla. A number of other peculiar misinterpretations of the source and type of sensory stimuli have been observed in our specially studied group of 20 patients, usually when analgesia was incomplete. These may be summarized as follows:

1) Rapid pinpricks and a variety of other stimuli over the analgesic half of the thorax and abdomen produced pain in corresponding areas on the normal side in four patients.

2) Squeezing the testicle on the analgesic side led to reference of pain to the opposite groin or to both buttocks in two patients.

3) Pulling the pubic hair on the analgesic side caused disagreeable sensation in the opposite hip.

4) Pain may be referred to regions higher up on the analgesic side than the point stimulated, e.g., compression of the Achilles tendon led to painful sensation in the analgesic hip; fast repeated pinpricks of an amputation stump of the right thigh evoked pain just to the right of the umbilicus.

All of these pains were much milder than those produced in normal persons by such stimuli.

Ray and Wolff (1945) reported corresponding findings in two patients after unilateral cordotomy. Pressure on a diseased hip joint, squeezing of calf muscles, and application of ice or a tube at 90° C. were the vigorous stimuli to the otherwise analgesic areas which caused pain referred to the opposite side in similar or nearby areas. This pain was much less severe than that produced in the normal area by such stimuli applied directly thereto, and appeared only after a slight but definite delay. It also outlasted the stimulus. Lesser thermal stimuli and pinprick in the analgesic side were ineffective in evoking pain on either side.

Holbrook and de Gutiérrez-Mahoney (1947) described similar signs in a patient after cordotomy in whom painful stimulation of the analgesic right side caused a peculiar pain, referred not only to the corresponding point on the normal left side but also to the left testicle. After a second cordotomy on the other side had yielded analgesia to T9, pinching or pinpricks over the analgesic areas of the left abdomen and thigh caused reference of pain to the abdomen above the analgesic level on that side.

nervated cutaneous areas. Other complaints such as deep aching or shooting pains were a further cause of frequent discomfort. While this complication has not been stressed in the literature,* it can be just as annoying a complication as the "anaesthesia dolorosa" that occasionally follows retrogasserian neurectomy. We have fortunately seen it in a really troublesome degree only twice in our series of over 300 cordotomies. The statement that the analgesic area feels as though it were icy cold is a rare complaint which we have encountered only once. This occurred after a high cervical cordotomy for malignant disease in the chest, with a very gratifying analgesia to the shoulder level (Mahmed Z., MGH U-728614). Fortunately this complaint gradually subsided and the patient hardly noticed it at 19 months.

Sjöqvist is the only other observer whom we find to have noted the incidence of these complications in a large series of cases. In five of his 71 cordotomies on 58 patients there was a disagreeable hot or cold sensation in the analgesic or hypalgesic area, and in six instances there was burning pain. One of Falconer's patients (personal communication, 1948) after high cervical cordotomy for pain in a phantom upper limb began to complain of burning pain below the costal margin only after this previously analgesic area became hypalgesic, and stimuli here had a peculiarly unpleasant quality. Our patients with the worst dysaesthesias had high cervical incisions. A similar condition, although of greater severity and much higher frequency, is reported below in the section on transection of the spinothalamic tract in the midbrain (see p. 284).

One may note in passing that Sicard, Haguenau, and Wallich (1927) describe the symptom of "isothermognosia," the transformation of all perceptions in the cordotomized territory into a uniform sensation of warmth. They regard this not as a complication but as the accompaniment of a clinical cure and as proof of a correctly performed cordotomy. We have rarely noted this in our own successful cases.

12. Allachaesthesia

The reference of sensation from analgesic skin to other areas is a curious misinterpretation of the origin of sensory stimuli. As an example of this phenomenon, a woman with a shoulder disarticulation and a painful phantom of her arm, which seemed to be drawn up in a cramped position behind her back, had been relieved of all discomfort for six months following anterolateral cordotomy at the first cervical level. The phantom unfortunately reappeared because her level of analgesia fell, with the appearance of islands

*We have found a single case reported by Oldberg (1932) in which tabetic crises were relieved with analgesia reaching to the sixth thoracic segments on both sides only to have the result marred by new aching pains in both groins.

had failed to bring relief. Not only in these 20 patients, but in the entire group as well, an analgesic level to within one or two segments of the tractotomy incision was rarely attained. This differs from Foerster and Gagel, who described this result after operation in 16 patients. Illustrations showing the extent of cordotomy in two of their cases, in which analgesia reached practically to the level of tractotomy, are reproduced in Figure 80.

Although in most of our patients no effort was made to raise the level of analgesia to its maximum height, our incisions in the cord were both deep and carried far ventromedially (Figs. 67 and 68). The results indicate that the level of the incision should be at least four and preferably six segments above the highest point at which pain is felt. Even this interval will not always suffice. As an example we cite a patient previously cordotomized on four occasions, twice on each side, by a distinguished neurosurgeon elsewhere (Patient 4 in Table XXXII). Although we found bilateral hypalgesia to T5, the only true analgesia was confined to the lower sacral segments of one side. In our subsequent unilateral cordotomy at the second thoracic segment the highest level obtainable after four incisions to increasing depth was just above the inguinal fold. Fortunately complete analgesia has persisted and he has continued to be relieved of his pain from lumbar arachnoiditis, not only in the analgesic zone, but in the contralateral hypalgesic limb as well.

2. Thermal Sensibility

Thermanaesthesia was more constantly complete than analgesia, as some residual awareness of heat was present only in three; partial sensation to both heat and cold was retained in but a single instance. Despite some residual awareness of temperature, three out of these four had complete freedom from pain; these three showed analgesia to pinprick in the previously painful area, whereas the fourth unrelieved patient was merely hypalgesic. Contrariwise, in two other patients with grossly inadequate relief of pain, thermanaesthesia was extensive. Insensibility to cold extended above the level of analgesia in 10, was the same in six, and a segment or two lower in four. In Banzet's series the zones of analgesia and thermanaesthesia were the same in 23 instances, analgesia was more extensive in nine patients, and thermanaesthesia more extensive in eight. Foerster and Gagel (1932) present evidence for ipsilateral as well as crossed transmission of temperature sensation. In some patients they noted but little impairment of thermanaesthesia despite desired analgesia after unilateral cordotomy. Then when the second side was cut there was full analgesia and thermanaesthesia on both sides. Sherman and Arieff (1948) have reported four cases of intra- and extramedullary disease of the spinal cord with preservation of tactile

It is apparent that spread of excitation in the spinal cord following noxious stimulation may involve less direct pathways to the brain in the same or opposite side. The presence of such pathways becomes apparent when the direct route is no longer available and the stimulus is intense. The person interprets these unusual stimuli, however, as though they had been transmitted along the usual direct paths.

D. SENSORY CHANGES AFTER ANTEROLATERAL CORDOTOMY

Careful determinations of changes in different modalities of sensation were made on 20 individuals five months to 10 years after radical anterolateral cordotomy. Nine patients had complete relief of their former pain,

TABLE IV

ANALYSIS OF PERSISTENT SENSORY CHANGES AFTER UNILATERAL ANTEROLATERAL CORDOTOMY IN 20 PATIENTS

(6 cases at 5 months to 2 years; 14 cases at 2 to 10 years)

ANALGESIA.	Complete to satisfactory level:	13	
	Incomplete in parts of the formerly painful area:	7	
THERMANAESTHESIA	Hot and cold lost at same level.	9	
	Hot lost 1-2 segments above cold:	7	
	No complete loss to hot:	3)	No clinical
	No complete loss to hot or cold:	1)	pain in 3

RELATION OF THERMANAESTHESIA (TO COLD) TO ANALGESIA: Higher in 10, same in 6, lower in 4, 1 with sacral sparing to cold with analgesia complete in this area.

TO[illegible] [illegible]hold: Perception of 0 5 gm [illegible] on analgesic side. Several [illegible] well on the analgesic as on the control side

PRESSURE PAIN ON BONE: Always reduced: Minimal rise in threshold from 26 lbs. per sq in. to 31 lbs ; maximal rise from 10 lbs. to unawareness of pressure of 52 lbs

POSITION SENSE: Unchanged

GRAPHAESTHESIA: Reduced in 1 case only.

TWO-POINT DISCRIMINATION· Sharp point: Greatly reduced. Dull point: Only slightly reduced

LOCALIZATION OF TOUCH: Normal in all but 2.

VIBRATORY SENSE Only minimally changed.

six minimal discomfort which required no medication, and two moderate pain which could be controlled by small amounts of medication; three were classified as failures. Their sensory changes are listed in Table IV.

1. Analgesia and Hypalgesia

Thirteen of the 20 had analgesia with complete unawareness of any sharp or disagreeable quality from the prick of a sharp pin. In seven analgesia was incomplete in parts of the painful area. In three of these the operation

i.e., the separation of the compass points necessary for discrimination was two to five times greater than that required on the normal side. In the remaining two patients there was only slight reduction of two-point discrimination using two sharp points. Of the three patients who were tested using blunt points, two showed only slight reduction and the other no reduction on the analgesic side. This may be related to the fact that a larger area of skin was stimulated by the corks than by the points. The location of the testing had no influence on the result, that is, there was equal reduction of two-point discrimination wherever the test was applied below the level of analgesia.

7. Tickle and Itching

The sense of tickle on the sole of the foot usually persists, although its intensity is often reduced. Some of our patients felt a deep pin scratch on the sole of the analgesic foot as a tickle, but did not have this sensation during light touch or light scratch as they did on the normal side. Peet (1926) mentions a patient whose tickle sense was pronounced on the sole of his analgesic foot. Foerster and Gagel (1932) went so far as to say that the tickle evoked by stroking of hairs, itch, and all pleasurable and unpleasant sensations were eliminated in the analgesic zone. Hyndman and Wolkin (1943) state almost the reverse, to wit, that tickle, "the sensation produced by lightly scratching the plantar surface of the foot," was neither abolished nor diminished in their 125 patients after cordotomy. These authors also state that patients do not shiver in their analgesic zones. In three patients they gave the rigorous test of putting the patient in a refrigerator at 0° to 5° C., which evoked vigorous shivering only in the nonanalgesic areas. Itch from a poison ivy dermatitis was abolished in the analgesic zone in one patient tested, confirming Rothman's (1943) claim that itch is a form of pain sensation. Hyndman and Wolkin (1943) have tested 10 patients with itch powder (from *Mucuna pruriens,* obtained in novelty stores) and found that itching was abolished in the analgesic area. One patient has been observed outside this series in whom an agonizing itch associated with an intramedullary neoplasm of the cord was abolished following anterolateral cordotomy. Banzet has reported a case of severe bilateral itching for 18 years with kraurosis vulvae and previous vulvectomy completely relieved by bilateral anterolateral cordotomy at T4 and T5 levels. Analgesia was complete on the left up to T8, but there was only slight hypalgesia on the lower leg and foot on the right. Relief was well maintained when the patient was last seen two and a half years after operation. Sicard and Robineau (1925) report another such patient with kraurosis vulvae in whom vulvectomy, x-ray therapy, and radium applications failed to stop the itching. Bilateral

sensation in which there was widespread dissociation of pain and thermal sensibility.

3. Tactile Acuity

The normal person feels the contact of a ¼ to ½ gram von Frey hair as a sense of light touch over hairless areas of the limbs and torso. On the analgesic side the threshold to touch was unaltered in some, slightly increased in the majority, and to a maximum of sixfold in one, who required the touch of a 3-gram hair. Tactile sensibility remains remarkably acute in hairy areas, so that the least contact is felt. We tell these patients that they will still be able to detect a mosquito when he alights, although they will not be able to feel him bite nor be annoyed by the subsequent itch. Kroll, working with the patients of Foerster and Gagel (1932, p. 45), often found increased threshold of touch (pressure) points and a decreased number of these points, as well as an almost constant increase in chronaxie on *both* sides after unilateral cordotomy. These changes were more pronounced on the side opposite the incision.

4. Pressure Pain

Perception of pressure pain over bone is always reduced. In some individuals a maximum stimulus of 50 pounds per square inch did not hurt on the analgesic side, while 10 to 25 pounds was painful at standard control points. In others the threshold for pain amounted to as little as 31 pounds on the analgesic side compared to 26 pounds on the control.

5. Vibratory, Proprioceptive, and Graphaesthetic Sensation

Vibratory acuity was never more than minimally reduced, and position sense was unchanged. Localization of touch remained normal in all but two cases. Graphaesthesia was reduced in only a single instance. These observations are essentially in agreement with those of Kroll.

6. Two-point Discrimination

Two-point discrimination was adequately tested in 14 patients using the two sharp points of a compass. In three of these two-point discrimination was likewise tested using two blunt points. For the latter tests the points of the compass were covered with corks, applied so that an area 1 to 2 mm. square was laid lightly against the skin. The separation of the compass points necessary to identify the two points was compared at corresponding locations on the normal and analgesic sides. Two-point discrimination using sharp points was moderately to markedly reduced in 12 of the 14 patients,

explain a number of failures to relieve suffering, as certain obscure disease processes may hurt in other ways than by the normal mechanism of pain ascending in the anterolateral tracts. One of our patients who stepped on a nail found that he was adequately warned by the reflex withdrawal of his analgesic foot. Whether sufficient sensation is still preserved to serve as a warning in appendicitis, inflammation of the gall bladder, or passage of a urinary calculus is still uncertain. However, we have seen no instances where such critical diagnoses have been missed on this score, and in patients with advanced malignant disease and its attendant complications accidents of this sort should certainly be reported. In a recent case of small intestinal obstruction occurring two months after a unilateral cordotomy for left-sided pain from recurrent rectal carcinoma, the patient noticed no pain on his analgesic side, although discomfort from distension was severe throughout the right side of his abdomen.

As pointed out above, the observations of cutaneous areas where single or rapidly repeated pricks with a pin may be felt as unpleasant but not sharp are of special importance. We believe that this often indicates the presence of a few residual pain-transmitting fibres in the contralateral anterior quadrant. Four patients with recurrence of severe pain, who would have passed as having a satisfactory level of total analgesia by the ordinary method of testing, have been relieved by secondary deeper incisions of the anterolateral quadrant.

E. VISCERAL SENSATION AFTER ANTEROLATERAL CORDOTOMY

That pain impulses from viscera usually travel in the anterior half of the cord is clear from a number of the older observations. Thus Foerster and Gagel (1932, p. 47) stated that if the anterolateral columns are completely divided, visceral pain is less likely to recur than that from the deep parts of the limbs. Hyndman and Wolkin (1943) found in four patients with bilateral analgesia of the legs and most of the torso that testicular compression was painless. In two of their patients with bilateral analgesia to T5 and to C8-T1 respectively artificial distension of the renal pelvis was painless. In one patient, however, whose bilateral cordotomy yielded analgesia only to T7, distension of either renal pelvis caused a severe bursting pain referred to the umbilicus. It is evident that when the pain is of visceral origin one must be careful to get the analgesic level above the highest zone of entry into the cord of the afferent fibres from the viscus.

Ranson and Clark (1947) in their textbook made the statement that, when the spinothalamic tract is cut on one side only, the analgesia of the opposite side of the body "involves the skin, muscles, fasciae, tendons and bones, but not the viscera. Bilateral section is required to abolish visceral

cordotomy at T5 was effective and the vulva looked much more normal seven months later. Kahn (1933) also reports relief of intolerable itching.

In general, after the most radical transection of the anterolateral quadrant almost no useful sensation is lost except discrimination of temperature. *There is no subjective numbness or unawareness of the analgesic extremity,* nor any difficulty in identifying small objects, selecting materials, or performing the finest movements with the eyes closed. The patient walking barefoot in the dark can tell whether he is walking on a stone or wooden floor, on a carpet or on linoleum. He must only beware that he does not step on a tack or burn his foot on a hot object. There has been no tendency in our cases to trophic changes, and injuries have healed in normal fashion.

8. Other Varieties of Stimuli Perceptible after Cordotomy

Certain other stimuli, however, are often capable of causing pain in "analgesic" zones (Table V). Stimulation with bipolar electrodes 2 to 3 mm. apart on the skin with 60-cycle current at from 40 to 140 volts is invariably disagreeable. This must be conducted over other pathways than the contra-

TABLE V

TYPES OF STIMULUS OFTEN CAUSING PAIN IN "ANALGESIC" ZONES

	Pain on Stimulus Absent	*Pain on Stimulus Reduced as Compared with Normal Side*
Achilles Tendon Pressure	6	6
Testicular Compression	2	8
Pressure on Bone (50 lbs./sq. in.)	9	7
Hair Pulling	17	3
Multiple Rapid Pinpricks	8	12*
Bipolar Electrical Cutaneous Stimulation (40-140 Volts)	—	20
Trauma: Fractured Ankle	—	1
Contusions to Thigh	—	1

*Two patients had recurrence of severe pain with appearance of small scattered areas of disagreeable sensation to the "repetitive pinprick test" Both of these have again been relieved by a secondary deeper cordotomy.

lateral anterolateral column. The disagreeable quality of testicular compression was diminished but rarely absent on the analgesic side after unilateral thoracic cordotomy; in one case it was present even after medullary tractotomy with analgesia complete to the chin. Hyndman and Wolkin (1943) also noted that squeezing the testicle on the analgesic side caused some pain in three of four patients after unilateral cordotomy. The fact that two patients were able to feel unpleasant sensations following ankle fractures and thigh contusion came as a distinct surprise. These observations doubtless

chronic persistent pain after multiple operations on the biliary tract and pancreas. This operation was performed 11 years ago, before we appreciated the effectiveness of sympathectomy in the relief of pain of purely visceral origin.

F. CAUSES OF FAILURE AFTER ANTEROLATERAL CORDOTOMY

As shown in Table IIC, 75 per cent of our patients maintained total or nearly total freedom from pain following interruption of the pain tract in the anterolateral column for periods of five months to 10 years, and an additional 10 per cent maintained sufficient relief to eliminate the need for narcotics. The early and late failures deserve special consideration.

In the first place, it is of interest to study the conditions which failed to respond following an adequate level and degree of analgesia. These are listed in Table VII. The psychoneurotic constitution of the first patient made any evaluation of her complaints impossible. The second and third patients, with painful leg and arm phantoms, continued to complain of their original symptoms, despite analgesic levels which were complete to T5 and C3. The former was severely addicted to narcotics, but the latter was not. It is, of course, impossible to determine by objective testing the interruption of all pain fibres from an amputated part. We are in complete disagreement with the opinion of Bailey and Moersch (1941) and many others that radical transection of the anterolateral column usually fails to relieve painful phantom sensation. Out of nine other sufferers from this condition in the lower extremity, seven have been relieved over periods of five months to two and a half years. Two others afflicted with painful phantom arms were relieved of their pain as long as analgesia above C5 was complete, but had recurrences at three months and three years respectively when analgesia was replaced by hypalgesia; a third remains free of pain at three years. The potential effectiveness of high cervical cordotomy in the relief of phantoms of the upper limbs has been substantiated by Falconer and Lindsay (1946).

Formerly we considered that cordotomy had a much diminished chance of success in patients taking large doses of opiates, but we now agree with Kahn and Peet (1948) that many of our failures attributed to drug addiction were due to continuing transmission of impulses of pain over other pathways. As soon as postoperative discomfort is gone patients whose pain is relieved will usually gladly abandon narcotics—often with marked improvement in their condition. This has been remarked upon by Frazier (1920), Leighton (1921), Banzet (1927), Stebbing (1929), and Grant (1932). Although one should consider cordotomy before placing the patient on a debilitating, habit-forming narcotic regime, the pre-existence of addiction is not necessarily a contraindication to operation.

The failure to relieve burning pain in the rectum and perineum in Pa-

pain." The failure of staggered hemisections on both sides of the cord to relieve biliary pain in dogs has been emphasized by Davis, Hart, and Crain (1929).

Our clinical data recorded in Table VI tend to disprove the hypothesis that one-sided pain from a viscus travels upwards in both anterolateral columns to a clinically significant extent. Seven patients with satisfactory unilateral analgesia were tested by retrograde ureteral catheterization and distension of the renal pelvis.* Injection on the control side of 8 cc. or more of fluid invariably produced pain and usually nausea, while a volume of 15 cc. was easily tolerated on the side of the analgesia. In five of these subjects no sensation of pain was noticed, while in two others mild discomfort without nausea was experienced after injection of 30 per cent more fluid than could be tolerated on the normal side. Distension of intestinal loops at different levels on the analgesic side with balloons inserted under fluoroscopic control* produced no discomfort in seven, while five others reported that milder pain was referred across the midline to the normal side. Similarly a recent patient (Calixte L., MGH U-780681 BM), on whom a right anterolateral cordotomy had been performed with a level of analgesia at T8 for recurrent carcinoma of the rectum and intolerable bouts of pain in his left lower abdomen and leg, developed acute intestinal obstruction from adhesive constriction of a loop of ileum in his pelvis. He re-entered the hospital vomiting and greatly distended, but said he could feel the bursting pain only on his right side. We have also had a patient under observation in whom left-sided anterolateral cordotomy gave complete relief from

TABLE VI

VISCERAL SENSATION AFTER UNILATERAL CORDOTOMY

Distension	*Sensation of Pain*	*No of Cases*
Distension of renal pelvis:	No pain:	5
	Reduced pain:	2*
Distension of small intestine by insufflation of balloon on analgesic side:	No pain referred to analgesic or to normal side:	7
	Reduced pain referred only to normal side:	5
Distension of small intestine by carcinoma after R. cordotomy:	No pain on L side (analgesic to T7), severe on R.:	1

*On control side 30% less fluid induced pain and nausea.

*We are indebted to Dr Walter S. Kerr and Dr. William P. Chapman for carrying out these tests.

tients 8, 9, and 10 we are at a loss to explain. Having failed to relieve an intensely disagreeable burning sensation in this area by a bilateral cordotomy in the first, a woman with ovarian cancer, we tentatively incised the anterolateral quadrant on a single side only in the other two, but could detect no benefit from the resultant hemianalgesia. We have therefore been reluctant to recommend cordotomy again for this unusual complaint. Petit-Dutaillis (1937), however, records a rare ano-rectal neuralgia in which the patient had a trigger zone on one side, touching which caused a paroxysm of pain. Unilateral cordotomy gave relief here. But in another patient of his with "neuralgia of the clitoris" cordotomy was a total failure. As to the failures with Patients 4, 5, and 6, we have learned by bitter experience that painful muscular spasm and cramping, which often accompany disease of the spinal cord, cannot be relieved by anterolateral cordotomy. Foerster and Gagel too, in their Case 27, record a failure in this type of problem. This is also often true of the pain occurring as a sequel to complete or partial transection of the cord, as exemplified by Jeremiah O. and Arthur T. While this is also the opinion of Davis and Martin (1947) from their extensive study of recent war injuries, pain in five patients following lesions of the spinal cord proper has been relieved according to the earlier reports of Frazier (1920), Case 2; Frazier and Spiller (1923), Case 8; Leighton (1921), Case 2; Banzet (1927), Case 27; and Foerster and Gagel (1932), Case 28. There is no question about the effectiveness of the operation after injuries of the cauda equina, where we have had complete relief in each of five patients with satisfactory high levels of analgesia (see Table XXXI). The single failure in Simon R. was due to inadequate denervation. Equally encouraging results have been reported by Foerster and Gagel, Case 24; Freeman and Heimburger (1947); Botterell *et al.* (1946); and Kahn and Peet (1948).

With the above exceptions there are few varieties of persistent organic pain in the lower part of the body which cannot be relieved by a well performed cordotomy. As seen in Table VII, our unexplained failures have been limited to two out of 14 individuals with pain in phantom limbs following amputation and cases of arachnoiditis, usually with added involvement of the spinal cord.

The following authors have also described patients whose pain was not relieved despite apparently adequate analgesia to pinprick:

Horrax (1929): Case 8, persistence of tabetic lightning pain in spite of bilateral analgesia to T5.

Frazier and Spiller (1923): Case 7, gunshot wound right sciatic nerve with analgesic right lower limb, but pain still in right thigh and foot.

TABLE VII

RETURN OF PAIN DESPITE ADEQUATE ANALGESIA—12 CASES

Patient	*Type of Lesion*
1. Jennie S. MGH U-1898	Persistent abdominal pain following nephropexy Severe psychoneurosis Subarachnoid lumbar block with procaine had not stopped this woman's complaints and should have served as a warning that cordotomy might fail
2. Frank I.* MGH U-552763 PH	Amputation stump neuralgia and phantom leg, following hip disarticulation for recurrent chondrosarcoma of acetabulum. No additional relief was obtained by section of ipsilateral posterior column of Goll, but patient was greatly improved by frontal leucotomy.
3. Robert S.* Worcester Hosp.	Post-amputation phantom hand following crush in machine Pain continued despite satisfactory level to C3.
4. Mary Y. MGH U-606632	Paget's disease with fracture T11 vertebra, and degenerative arthritis of hip Painful flexor spasms in legs due to cord lesion.
5. Frank T. MGH U-205110 PH	Diabetes and combined system disease. Painful flexor spasms in legs due to cord lesion.
6. Matthew B. MGH U-647982	Degenerative arthritis of spine and legs with ascending arachnoiditis, which developed after an unsatisfactory osteotomy of T12 vertebra Bilateral cordotomy eliminated all pain on movement of back and legs, but had no effect on cramping pain associated with involuntary muscular spasms.
7. George P. MGH U-180510 BM	Left-sided sacral neuralgia of unknown origin which had been treated by intrathecal injection of alcohol at another hospital. Severe sacral arachnoiditis discovered at exploratory laminectomy. Failure of cordotomy despite analgesia to T8
8. Clara E MGH U-253448 BM	Carcinoma of ovary with persistent perianal and perineal discomfort which failed to improve following an otherwise satisfactory cordotomy
9. Hamilton I. MGH U-629098 BM	Arachnoiditis with residual burning pain in rectum and perineum. Relieved subsequently by unilateral frontal leucotomy (Dr J. E Scarff), but pain ultimately recurred.
10. Sara B. MGH U-487268 BM	Lumbosacral arachnoiditis following spinal injury, exploration and fusion. This woman's perianal and perineal burning was in no wise benefited by a unilateral cordotomy, although pain radiating to leg improved.
11. Jeremiah O. MGH U-521939 BM	Pain from complete crush of midthoracic cord not relieved by subsequent resection of scarred rostral end of severed cord
12. Arthur T.* MGH U-569089 BM	Old tuberculosis of spine with kyphos and cord compression at T7.

*In these patients it was impossible to test for residual islands of perception of repetitive pinprick.

there was an erroneous prediction of failure in a patient who had no relief from two spinal anaesthetics during which loss of sensation extended to T11 and T4 respectively. This man's thigh amputation stump and phantom pain, nevertheless, responded well to operation. Further experience with the test is therefore essential, and it must be borne in mind that injections of procaine may be dangerous in persons with arachnoiditis or other forms of intraspinal disease. At present, therefore, we have no certain method of picking in advance the rare individual who will fail to derive a satisfactory result following a technically adequate cordotomy.

In order to ensure the success of the procedure it is our opinion that the most important step is to establish the level of analgesia at the time of operation. The initial incision is rarely deep enough. A second or even a third is usually necessary, and at times all of us have been forced to make additional incisions of progressively greater extent. It is therefore vital that every attempt be made to perform this operation under local anaesthesia, or under local supplemented by Pentothal and nitrous oxide or Trilene (see p. 208), and the patient given time to awaken. When this is done, a very small number will be too uncooperative or confused for satisfactory testing on the table. The depth and extent of incision must then be a matter of judgment. If the result is unsuccessful, the incision should be reopened on the following day in order to deepen the cordotomy and extend it further forward towards the midline, if the level of analgesia is low, or dorsally if the fibres just anterior to the dentate have been missed with sparing of sacral sensation.

In the earlier years of this series our efforts to establish an accurate sensory level at the time of operation were not as painstaking as at present. Nevertheless, it has been possible to carry out the test on nearly two-thirds of the total series.* Neglect to do so has doubled the risk of early failure in our hands. Unfortunately, this precaution does not eliminate later failure caused by a drop in the level of analgesia due to mere contusion without complete transection of the pain fibres. If the level of analgesia is tested at frequent intervals during the first hours after cordotomy, it may be found to climb several segments. This is due to the spread of oedema beyond the plane of transected fibres. Analgesia will drop within a few days to at least its original level and may prove deficient in more caudal dermatomes if certain groups of fibres have been contused but not transected at operation. At times, however, analgesia will give way to hypalgesia only after a period

*Actually the proportion of patients in whom it has been possible to test the sensory level satisfactorily on the operating table has increased to over 90 per cent in the last two years. This has been made possible by routinely supplementing local anaesthesia with light Pentothal or intravenous Demerol and Trilene or nitrous oxide. If the surgeon is patient, very few individuals fail to awaken sufficiently to cooperate and respond intelligently on sensory testing.

Banzet (1927): Case 22, pain in amputation stump of lower leg despite analgesia to T12.

Banzet (1927): Case 28, pain in both legs after bullet wound of cauda equina, although analgesia rose to T10 on one side, L2 on the other.

Foerster and Gagel (1932): Cases 1 and 9, tabetics with continuing gastric crises despite bilateral cutaneous analgesia to T5 and T2 respectively.

Foerster and Gagel (1932): Case 13, pain in amputation stump of fifth finger despite analgesia to C2.

Foerster and Gagel (1932): Case 15, pain in sole and heel after tibial nerve injury returned three months after cordotomy, although appreciation of pinprick did not come back until 22 months postoperatively.

Foerster and Gagel (1932): Case 22, pain in arm from metastatic carcinoma of axilla, although cutaneous analgesia (without thermanaesthesia) extended to the upper border of C3 segment.

Our experience leads us to think that the patients with neoplasm, tabes, or injury to peripheral nerves might have felt pain on more vigorous stimulation than single pinpricks (as was in fact recorded in all five cases of Foerster and Gagel). *Such cases might all have been relieved by more extensive* cordotomy on one or both sides.

In an attempt to develop a satisfactory method of eliminating failures where the focus of pain may be central (i.e., within the spinal cord, thalamus, or cortex), rather than peripheral, we have tried preliminary subarachnoid spinal block with procaine. This interrupts conduction in the spinal and caudal sensory roots, but does not penetrate deeply into the cord. Beer (1913) was probably the first to try this. A subarachnoid injection of stovain temporarily stopped the pain, which was then permanently relieved by an effective cordotomy. Horrax (1929) also relieved arthritic pain briefly by a spinal anaesthetic in the first of his series of cordotomies.

Our first attempts with differential blocking of the finer calibre, less heavily myelinated pain fibres in the spinal roots by low concentrations of procaine, as suggested by Sarnoff and Arrowood (1946), were most misleading. In some cases, which later responded well to cordotomy, the pain was actually increased. When 150 mg. of procaine dissolved in 4 cc. of spinal fluid were injected the temporary effect corresponded fairly well with the final outcome of tractotomy. Sir Geoffrey Jefferson (personal communication, 1950), who has been employing this test since 1924, states that he has been impressed by its effectiveness. In our experience with 10 cases, a favourable result was correctly predicted in eight and a poor result foretold in one (the psychoneurotic Patient 1 of Table VII). On the other hand,

island of hypalgesia over the knee at five months. Horrax's still showed analgesia to T10 eighteen months after cordoto but at 26 months this had faded to hypalgesia from T10 to aesthesia" from L4 to S5. An additional deeper cordot pain and restored the analgesia. In Foerster and Gagel's cutaneous analgesia to T8, still present at 20 months, later gave way hypalgesia. Kahn (1933) commented that pain sense may return in an area originally analgesic within a few weeks to a few years. This type of behaviour is the exception in our experience. More encouraging findings

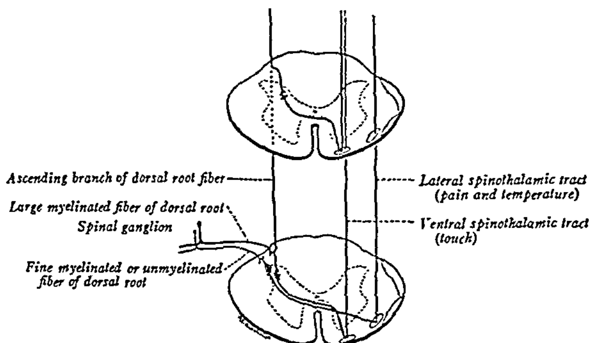


Fig. 79. Anatomical diagram from Ranson and Clark's textbook to show *their concept of* limited area in anterolateral column occupied by the lateral spinothalamic pain and temperature tract.

From Ranson and Clark, 1947. Courtesy, W. B. Saunders Co., Philadelphia.

were seen in our special late follow-up group, examined fully two to 10 years after operation; of these 15 patients only three showed sizable zones of recovery of appreciation of sharpness of individual pinpricks. The duration of follow-up for the whole group averaged 65 months and the last examination in four of those who maintained their sensory loss was over nine years after cordotomy. A high thoracic operation was done in 14 of 15 (the lone high cervical operation has yielded a constant level at C5 for over six years). On the basis of this experience we think that the likelihood of maintenance of relief of pain is greater following upper thoracic cordotomy than after any other operation we know of on the central neuraxis.

Anterolateral cordotomy has been accused of yielding a high proportion of unsatisfactory results. In addition to the frequent failure to establish a

of months. This is well illustrated by the sensory diagrams in Figure 78. *In this woman, carefully re-examined on four occasions over a period of* three and a half years, there was a striking recession in the area of total analgesia. Fortunately the postoperative neuralgia from multiple bilateral upper thoracic sympathectomies did not recur, because full analgesia to high-grade hypalgesia persisted in the area of the surgical scars. We have no explanation to offer for the gradual return of sensibility to other wide areas of this woman's body. Nearly a year had gone by before the ability to detect the sharp quality of the tip of a pin and awareness of cold began

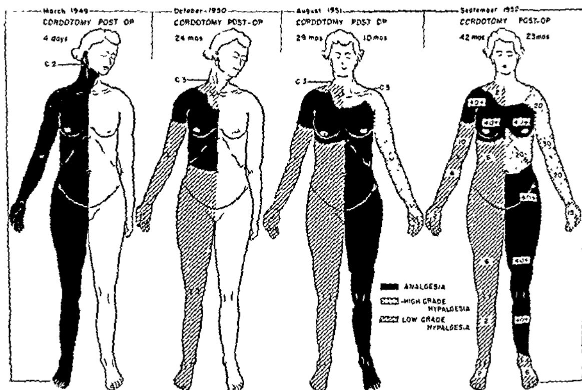


Fig. 78. *Progressive recovery of sensibility to pinprick after initial complete bilateral transections of the spinothalamic tracts.*

In the right-hand figure pricks of known intensity were made with a spring algesiometer and are recorded in grams

Appreciation of heat was permanently lost over the entire hypalgesic skin, but at her last testing the patient was able to identify cold objects everywhere but in the full analgesic area.

to recover. When analgesia fades, a variable degree of hypalgesia is left in its place, often insufficient to prevent return of pain. This late increase in pain conduction is the hazard which the skillful surgeon has most to fear. We have now reoperated on a number of these later failures with gratifying success.

This rare late return of algesia has been a recognized problem since the early years of cordotomy. Frazier and Spiller (1923) cited a patient with analgesia to the inguinal ligament six weeks after operation who showed an

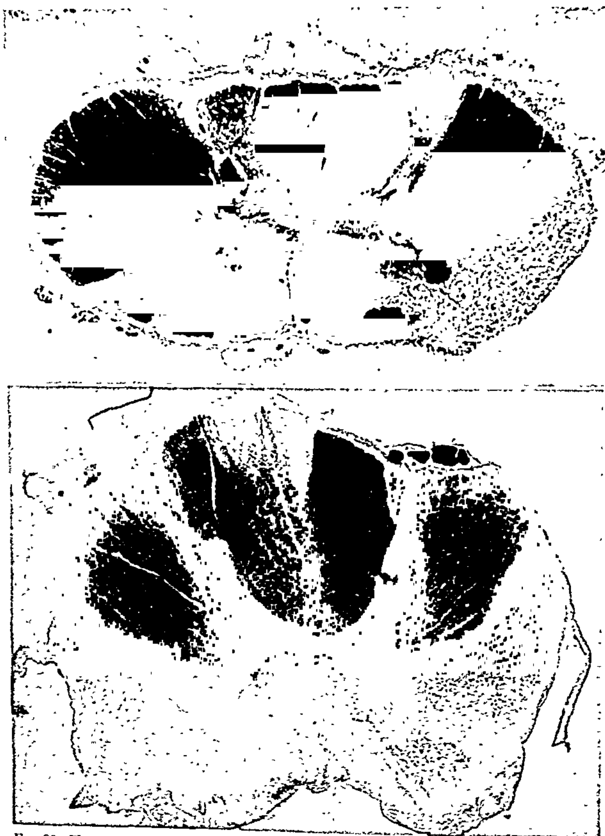


Fig. 80. Photomicrographs of two extensive anterolateral cordotomies from article by Foerster and Gagel (1932).

A (*upper*). Unilateral section at the upper level of the third thoracic segment.

B (*lower*). Bilateral section at the level of the fifth thoracic segment.

From Foerster and Gagel: *Z. ges. Neurol. Psychiat.*, 1932 Courtesy, Springer-Verlag, Berlin.

satisfactory level of analgesia by testing the patient at the time of operation, it is the practice of many surgeons to make the laminectomies too low in the back and not to start their cordotomy incision close enough to the dentate ligament; nor to carry it to a sufficient depth or far enough ventromedially. Inaccurate illustrations in current medical textbooks such as Figure 79, reproduced from Ranson and Clark's neuroanatomy (1947) have represented the spinothalamic tract compressed into a tiny, compact fascicle in the lateral portion of the cord and occupying only a small portion of the area between the dentate ligament and the anterior root. Reference to the photomicrographs of two of our actual sections in Figure 77 shows that transection of this area will not necessarily produce either a high level of sensory loss or complete analgesia. The patient whose cordotomy is depicted in Fig. 77A had only hypalgesia with persistence of pain in the thigh, and after the incision illustrated in Figure 77B analgesia extended only to the tenth thoracic dermatome.

The impression has gradually been forced upon us that the extent of the pain tract must vary considerably in different individuals. Foerster and Gagel's massive lesions, reproduced in Figure 80, gave a level of analgesia which rose to within two spinal segments of the incision, but in our experience this has not necessarily followed. Figure 68 proves that there may be a much wider variation in the number of spinal segments required by the secondary pain fibres to decussate and take up their position in the opposite anterolateral column where they can be cut. Here are shown two equally extensive lesions made at the level of the second thoracic vertebra. Both extend dorsally somewhat beyond the line of the dentate ligament and include nearly the entire anterior quadrant. The section shown in the photomicrograph, Figure 68A, which stops over a millimeter short of the midline, gave analgesia to the fourth thoracic dermatome, while the other, Figure 68B, which was nearly as complete in every other respect and carried right up to the midline, produced analgesia only to T8, six spinal segments below. In a few cases repeated contralateral cordotomies have led us to the conclusion that it is sometimes impossible to raise the level of analgesia above the lower thoracic segments, no matter how deeply the anterior quadrant of the cord is incised at the first or second thoracic level. There is usually no difficulty in obtaining a high level of hypalgesia, but true analgesia may be quite another matter.

Evidence which we have obtained at operation (Sweet, White, Selverstone, and Nilges, 1950) shows that electrical stimulation of the anterior quadrant with extremely fine bipolar electrodes may give very variable pain responses. The electrodes were inserted 1, 2, and 3 mm. anterior to the plane of the dentate ligament and to depths varying from 1 to 5 mm. Square waves of 30-per-second frequency and 1 millisecond duration were

It therefore appears that the pain fibres are diffused over a very wide area of the anterolateral quadrant, and that at times some centrally conducting fibres must run upwards in the ipsilateral as well as in the contralateral columns, at least for a considerable distance.* For these reasons we would advocate that, when a secondary cordotomy has to be done to correct a previous failure and when the first operation has been properly performed, it is wise to make the second attempt at a high level, if possible eight to 10 segments above the highest reference of pain, and to observe the effects of electrical stimulation with the need for an ipsilateral cordotomy in mind.

On the basis of direct stimulation of the secondary pain-conducting fibres and the comparison of visualized lesions with the established level of analgesia, it is evident that the necessary extent of incision must vary considerably from one individual to another, and that in certain rare instances a level of analgesia above the xyphoid or even the umbilicus cannot be produced by transection of the entire anterior quadrant in the upper thoracic cord. This means that to achieve a satisfactory proportion of effective results the surgeon must place his cordotomy a good six segments above the uppermost extent of the painful area, and be prepared to make a radical incision in the cord and verify the extent of resultant sensory loss on the operating table. There is fortunately no evidence that widening the extent and increasing the depth of cordotomy appreciably raises the incidence or severity of postoperative complications, as long as one remains ventral to the dentate ligaments and lateral to the anterior spinal artery.

Inadequate postoperative testing to determine the completeness of analgesia is another cause for unjust condemnation of the procedure. It is our contention that analgesia, to be effective, must be complete as well as adequate in extent. While pain may occasionally be relieved in the presence of high-grade hypalgesia, this is not generally the case. There is presumptive evidence that the cordotomy incision has been incomplete if a single vigorous prick or the continuous scratch of a sharp pin evokes any quality of disagreeable sensation, even over small cutaneous islands. Furthermore, in the early postoperative period rapid repetitive pinprick should produce no sense of sharpness or discomfort. Careful stimulation of the entire "analgesic" zone is essential. If any islands of dysaesthesia are present it is unfair to blame the operation for the continued presence of pain, because it will usually disappear after a more radical tractotomy. In the case of resistant stump neuralgias and painful phantoms, where the effectiveness of cordotomy has so often been questioned, it is manifestly impossible to make certain that analgesia is complete in the amputated area.

*This has been substantiated clinically in two remarkable case reports by French and Peyton (1948) and by Voris (1951), where unilateral cordotomies resulted in an entirely ipsilateral loss of pain and temperature sensation.

generally effective at potentials of 1 to 3 volts. Responses obtained from 200 stimulations within the anterolateral quadrant of the cord in 23 cooperative patients are available for analysis.

The sensations evoked were pain in 54 per cent and feelings of heat in 37 per cent, cold in the remaining 9 per cent. In a general way, the deeper and more ventral the electrodes were placed the higher up in the body the sensation was felt;* furthermore, there was no tendency for the painful responses to disappear as the electrodes were moved to the most medial and ventral positions at depths of 4 to 5 mm. At these deeper placements of the electrodes close to the midline, the pain might be referred ipsilaterally or to both sides simultaneously.

This experience corroborates our clinical impression that in order to obtain consistently an effective high and permanent level of analgesia it is necessary to transect virtually the entire anterior quadrant. A surprising feature of our observations during electrical stimulation is that pain was referred to the ipsilateral side in 12 per cent and to both sides of the body in 6 per cent. There is a tendency for these uncrossed fibres to be concentrated in the most medial portion of the area stimulated. We have shown the presence of a few ipsilateral pain fibres to be of clinical significance in one clear-cut instance. In this man (John R., NECH #43-917) an initial right cordotomy at T3 segment done elsewhere had yielded analgesia up to the seventh rib except for the left anoperineal region and medial buttock; pain persisted in this hypalgesic area. We performed another right cordotomy at T2 which neither altered the zone of sacral sparing nor helped the pain, although we thought the cut extended from immediately ventral to the dentate ligament 5 mm. deep to incise the whole anterior quadrant. The cord was exposed a third time; stimulation within it 2 mm. ventral to the dentate ligament and 2 mm. deep in the side ipsilateral to the pain and at the T1 segment caused an electrical tingling in the patient's ipsilateral knee. With this evidence for some uncrossed pain fibres, an extensive cordotomy was carried out on the left side at the first thoracic level. Following this there was analgesia to single pinpricks on the right side everywhere below the fourth rib; the sacral segments on the left were now analgesic as well, and there was no pain below the waist till the patient's death five months later.

---

*In a typical case (Mary B., NECH #49-701) stimulation of the left anterolateral quadrant was carried out at different depths in a plane just anterior to the dentate ligament. This patient was under local anaesthesia, fully responsive, and gave an accurate description of her sensations With the Grass stimulator yielding square waves of 1 millisecond duration, 30 cycle frequency, and 1 volt intensity, the patient noticed the following effects: at depth of 1 mm., severe pain in right leg up to knee, at depth of 2 mm., pain from right sole to right hip, at depth of 3 mm., pain in left foot and right hip, "a shuttling back and forth from one side to the other"; at depth of 4 mm., pain in right hip and right back, or possibly in both sides of back.

TABLE VIII

SPINOTHALAMIC TRACTOTOMY IN THE MEDULLA (6 CASES)

Patient	Age	Condition	Pain Reference	Date	Site of Operation	Side	Complications	Sensory Level	Result
1. Jeannette S. MGH U-10469	31	Postoperative neuralgia after multiple thoracic sympathectomies for Raynaud's disease.	Occiput, neck, shoulder, and upper chest, R.	10/40	Below lowest vagal rootlet	L.	Ataxia (temporary).	Analgesia C 1 eventually receding to T 1. Hypalgesia and thermanaesthesia to C7.	Complete relief at 12 yrs.
2. Percy J. Queen Elizabeth Hosp., Birmingham, England	41	Amputation arm below shoulder.	Phantom arm and hand.	5/43	2 mm. below obex.		Paraesthesia in face on side of incision.	Analgesia C3	Complete relief for 3 yrs. with recurrence as level fell at 5 yrs.
3. Mary C. MGH U-412312	63	Carcinoma breast with supraclavicular and pulmonary metastases.	Pain in swollen, paralyzed arm, shoulder, and neck, L.	11/45	8 mm. below obex.	R.	None.	Analgesia C 1	Relieved first few weeks, but pain recurred as level fell. Died at 7 mos.
4. Blanche M. MGH U-480674	42	Carcinoma of oesophagus.	Upper chest and neck, R.	12/45	1 cm. below obex.	L.	None.	Analgesia C 1	Relieved but died a week later of haemorrhage from erosion of subclavian vein.
5. Everett D. MGH U-518611	55	Fibrosarcoma of L. shoulder and neck with pleural and pulmonary metastases. Preoperative paralysis of L. phrenic and vagus nerves.	Neck, arm, and chest, L.	10/46	5 mm. below obex.	R.	Tumour infiltration L. jugular vein, generalized convulsion and death on second day.	Analgesia to highest cervical dermatome on L. with loss of pain in R. forehead and cornea.	Relieved of pain. Operative death. Post-mortem showed bronchopneumonia. Medullary incision shown in Fig. 71.
6. John K. MGH U-542349	56	Carcinoma of oesophagus.	Shoulder and posterior scapula, R.	1/47	3 mm. below obex.	L.	Fall in blood pressure and sudden death immediately after medullary incision.		Operative death; no post-mortem.

G. RESULTS OF SPINOTHALAMIC TRACTOTOMY IN THE MEDULLA

Results of spinothalamic tractotomy at the medullary level are shown in Table VIII. There were two operative fatalities in this group. In Patient 5 death followed a generalized convulsion on the second day after operation, and tumor invasion with recent thrombosis of the jugular vein was found at postmortem. Examination of the medulla (Fig. 71) revealed a satisfactory incision, except that its dorsal extent was somewhat excessive and included a large part of the descending spinal root of the trigeminus. This patient had analgesia of the forehead and cornea on the side of the incision, as well as crossed loss of pain and temperature sensation below the chin. He was observed to have some difficulty in swallowing, which may well be accounted for on the basis of traumatic oedema in the region of the nucleus ambiguus combined with the fact that he had pre-existent paralysis of the opposite vagus from the growth in his neck. In Patient 6 a severe fall in blood pressure followed immediately after the medullary incision was completed, with cessation of respiration and heartbeat occurring a few minutes later. Both of these patients were in the late stages of malignant disease and exceedingly poor operative risks. In the other five, similar incisions gave rise to no serious complications. Crawford (1947) and D'Errico (1950), who have reported the only other series of medullary tractotomies, had three deaths in 23 cases. The single death in D'Errico's series occurred immediately after operation and was ascribed to a coronary thrombosis, the two in Crawford's 11 operations resulted from medullary oedema after bilateral incisions were made at a single stage. It is dangerous to do this either in the medulla or in the upper cervical segments for reasons given above.

The only troublesome complaint in our surviving patients was the ataxia in Patient 1, which ultimately cleared. Here the tractotomy was made at the level of the last vagal rootlet. As a similar complication was often experienced after Sjöqvist's operation on the descending trigeminal tract when carried out at the same rostral level, it became obvious, as Grant and Weinberger (1941A) pointed out, that a more caudal incision must be made in order to avoid damage to the vestibular nuclei and restiform body. Since this precaution has been adopted we have had no further difficulty on this score. Recovery in the others has been remarkably smooth. Several of these individuals have noticed hypalgesia of the face, particularly in the ophthalmic division, on the side of the incision, but this has not been a cause of complaint. This is due to the fact that the most dorsal fibres of the pain tract at this level are in close contact with the descending root of the trigeminus (Fig. 60). We have deliberately extended our incision posteriorly to the point where the patient first mentions facial pain in order to ensure complete transection of the spinothalamic fibres.

TABLE VIII

SPINOTHALAMIC TRACTOTOMY IN THE MEDULLA (6 CASES)

	Patient	*Age*	*Condition*	*Pain Reference*	*Date*	*Site of Operation*	*Side*	*Complications*	*Sensory Level*	*Result*
1.	Jeannette S. MGH U-10469	31	Postoperative neuralgia after multiple thoracic sympathectomies for Raynaud's disease.	Occiput, neck, shoulder, and upper chest, R.	10/40	Below lowest vagal rootlet	L.	Ataxia (temporary).	Analgesia C 1 eventually receding to T 1. Hypalgesia and thermanaesthesia to C7.	Complete relief at 12 yrs.
2.	Percy J. Queen Elizabeth Hosp., Birmingham, England	44	Amputation arm below shoulder.	Phantom arm and hand.	5/43	2 mm. below obex.		Paraesthesia in face on side of incision.	Analgesia C3	Complete relief for 3 yrs. with recurrence as level fell at 3 yrs.
3.	Mary C. MGH U-412312	63	Carcinoma breast with supraclavicular and pulmonary metastases.	Pain in swollen, paralyzed arm, shoulder, and neck, L.	11/45	8 mm. below obex.	R.	None.	Analgesia C 1	Relieved first few weeks, but pain recurred as level fell. Died at 7 mos.
4.	Blanche M. MGH U-480674	42	Carcinoma of oesophagus.	Upper chest and neck, R.	12/45	1 cm. below obex.	L.	None.	Analgesia C 1	Relieved but died a week later of haemorrhage from erosion of subclavian vein.
5.	Everett D. MGH U-548611	55	Fibrosarcoma of L. shoulder and neck with pleural and pulmonary metastases. Preoperative paralysis of L. phrenic and vagus nerves.	Neck, arm, and chest, L.	10/46	5 mm. below obex.	R.	Tumour infiltration L. jugular vein, generalized convulsion and death on second day.	Analgesia to highest cervical dermatome on L. with loss of pain in R. forehead and cornea.	Relieved of pain. Operative death. Postmortem showed bronchopneumonia. Medullary incision shown in Fig. 71.
6.	John K. MGH U-542349	56	Carcinoma of oesophagus.	Shoulder and posterior scapula, R.	1/47	3 mm. below obex.	L.	Fall in blood pressure and sudden death immediately after medullary incision.		Operative death; no post-mortem.

G. RESULTS OF SPINOTHALAMIC TRACTOTOMY IN THE MEDULLA

Results of spinothalamic tractotomy at the medullary level are shown in Table VIII. There were two operative fatalities in this group. In Patient 5 death followed a generalized convulsion on the second day after operation, and tumor invasion with recent thrombosis of the jugular vein was found at postmortem. Examination of the medulla (Fig. 71) revealed a satisfactory incision, except that its dorsal extent was somewhat excessive and included a large part of the descending spinal root of the trigeminus. This patient had analgesia of the forehead and cornea on the side of the incision, as well as crossed loss of pain and temperature sensation below the chin. He was observed to have some difficulty in swallowing, which may well be accounted for on the basis of traumatic oedema in the region of the nucleus ambiguus combined with the fact that he had pre-existent paralysis of the opposite vagus from the growth in his neck. In Patient 6 a severe fall in blood pressure followed immediately after the medullary incision was completed, with cessation of respiration and heartbeat occurring a few minutes later. Both of these patients were in the late stages of malignant disease and exceedingly poor operative risks. In the other five, similar incisions gave rise to no serious complications. Crawford (1947) and D'Errico (1950), who have reported the only other series of medullary tractotomies, had three deaths in 23 cases. The single death in D'Errico's series occurred immediately after operation and was ascribed to a coronary thrombosis; the two in Crawford's 11 operations resulted from medullary oedema after bilateral incisions were made at a single stage. It is dangerous to do this either in the medulla or in the upper cervical segments for reasons given above.

The only troublesome complaint in our surviving patients was the ataxia in Patient 1, which ultimately cleared. Here the tractotomy was made at the level of the last vagal rootlet. As a similar complication was often experienced after Sjöqvist's operation on the descending trigeminal tract when carried out at the same rostral level, it became obvious, as Grant and Weinberger (1941A) pointed out, that a more caudal incision must be made in order to avoid damage to the vestibular nuclei and restiform body. Since this precaution has been adopted we have had no further difficulty on this score. Recovery in the others has been remarkably smooth. Several of these individuals have noticed hypalgesia of the face, particularly in the ophthalmic division, on the side of the incision, but this has not been a cause of complaint. This is due to the fact that the most dorsal fibres of the pain tract at this level are in close contact with the descending root of the trigeminus (Fig. 60). We have deliberately extended our incision posteriorly to the point where the patient first mentions facial pain in order to ensure complete transection of the spinothalamic fibres.

II. RESULTS OF TRACTOTOMY IN THE MESENCEPHALON

In addition to the four cases in which Dogliotti cut the tract at a somewhat lower level, we know of 24 experiences with its transection at the base of the superior colliculus by others and five of our own. These cases are summarized in Table IX.

In all but two of the reported cases analgesia or a sufficient degree of hypalgesia has been produced to give effective relief of pain in the face and neck. It is surprising that only a mild degree of hypalgesia should relieve the intense pain of cancer with radiation fibrosis, as in the patient discussed by Grant (see Walker, 1942A), since this is generally not the case after anterolateral cordotomy. Perhaps the pain would have returned had these patients survived for longer periods. It is also of interest that in several of the reported protocols analgesia, which was more or less complete over the facial and cervical dermatomes, tended to fade out in the lower thorax. This can be explained anatomically by what we know from Walker regarding the somatotopic arrangement of the spinothalamic axones. Those supplying the lower half of the body lie most dorsally. A cut made in the lateral sulcus thereby severs the pain fibres coming from the face* and upper half of the body, but fails to divide those from the inferior portion unless the cut passes dorsally through the complete extent of the brachium of the inferior colliculus. As the operation is usually undertaken to sever the secondary trigeminal and cervical connections, this possibility of making a selective section of the tract is a most fortunate one. Evidence to corroborate this is given in several of Walker's cases and in 4 of our patients. However, the failure to maintain analgesia shown in most of the cases surviving a few months strongly suggests that the possible pain pathways at this level are more diffuse than they are lower down. Head and Holmes (1912) drew attention to this diffuseness, observing that lesions of the spinal cord tend to diminish simultaneously all forms of pain sensibility, whereas with disease of the brain stem pressure, pain, and unpleasant heat *may* be appreciated, although the skin is analgesic. We need to know more about the anatomy of the pain fibres in this region.

No difficulties with micturition or weakness of the leg have been reported, thanks to the wide separation between the pain fibres and the descending autonomic and corticospinal pathways. Sensory examinations made after this operation, as after anterolateral cordotomy and medullary tractotomy, have shown only minimal disturbances in light touch and no obvious loss of other important sensory modalities. Loss of discrimination to heat and cold corresponds with the area of hypalgesia A unilateral incision, while cutting the lateral lemniscus and brachium of the inferior colliculus,

*Walker has found that experimental histamine headache, which is transmitted by trigeminal fibres from the meninges, is not felt *after this* operation

Unfortunately it is not easy to establish and maintain a high cervical analgesia. Indeed, just as high and lasting levels have been obtained in the patients where we have found it impossible to make the section in the medulla and have chosen the level of the second posterior root instead. The highest level of persisting total analgesia, at the third cervical dermatome, was obtained by this type of cordotomy in Patient 4 (Table XXXIV, Chap. XVII). After the medullary tractotomy in Patient 1, although relief of a severe postoperative cervical and upper thoracic neuralgia has remained complete for 10 years, analgesia has fallen to the axilla and inner arm (T1) and hypalgesia to the lower cervical dermatomes. In Patient 2 analgesia remained above the level of the brachial plexus for three years, only to fall thereafter with recurrence of pain in the phantom arm. In Patient 3 the sensory level fell after a few weeks with return of supraclavicular pain. Therefore on the basis of our own statistics we have no right to claim that spinothalamic tractotomy, even at the medullary level, can ensure a permanent interruption of pain in the neck and shoulder.

Crawford (1947), who has reported the results of this operation in 11 cases, was able to obtain enduring levels of analgesia as high as the third cervical dermatome in several cases with relief of pain from metastatic carcinoma of the cervical spine and shoulder. D'Errico (1950) has been able to obtain very high total analgesia by extending his cut posteriorly, as well as deeply (6 5 mm.), to a point where pain is felt in the ipsilateral face due to contact with the descending trigeminal root. One patient, according to a recent letter from D'Errico, maintained a complete level at the mandibular margin until her death two years later. Another, in whom the upper limit of analgesia had been deliberately placed at the third cervical dermatome, has maintained this with freedom of pain in his phantom arm for four years. The others, cases of carcinoma of the lung, breast, and neck with invasion of the brachial plexus, failed to survive for such long periods, but were relieved of their preoperative pain. All except a single patient came through the operation and showed no ill effects, except for transitory ataxia. This may be explained by the fact that the incision was made at the olivary level. D'Errico adds that he has recently been able to carry out a differential intramedullary section in two cases, obtaining analgesia only in the upper part of the body.

From the experience with the four deaths which have followed these deep lateral medullary cuts it is obvious that the size of the incision must be controlled with extreme care. This requires considerable experience as well as skill on the part of the surgeon, a favourable distribution of the pial blood vessels at the side of the medulla, which we consider important to preserve, and a cooperative, responsive patient in whom the level of analgesia can be verified.

Case 2.	Intercostal neuralgia of unknown origin following many operations.	Mesencephalic tractotomy.	Entire contralateral side.	Neuralgia relieved.	Burning paraesthesia as severe as original pain.
Case 3.	Pancoast superior pulmonary sulcus tumour.	Mesencephalic tractotomy.	Entire contralateral side.	Neuralgia relieved.	Burning paraesthesia as severe as original pain.
Case 4.	Carcinoma of maxilla.	Mesencephalic tractotomy.	Entire contralateral side.	Temporary relief but recurrence with incomplete analgesia.	Secondary rhizotomy of cranial nerves V and IX and upper cervical posterior roots necessary.
Case 5.	Carcinoma of nasopharynx.	Mesencephalic tractotomy.	Entire contralateral side.	Relief to death in 6 wks.	None.
Case 6.	Pancoast tumour.	Mesencephalic tractotomy.	Entire contralateral side.	Complete relief at 3 mos.	None.
Grant (see Walker, 1942B)					
	Pulmonary cancer with supraclavicular metastases.	Mesencephalic tractotomy.	Hypalgesia only from upper cervical to T8 level.	Great relief of pain.	
David, Talairach, and Hecaen (1947)					
	Postherpetic neuralgia of arm.	Mesencephalic tractotomy.	Contralateral analgesia to deep and superficial pain; precise extent not studied.	Died in 3 days	Contralateral homonymous hemianopsia and muscle weakness; pneumonia.
Guiot and Forjaz (1947)					
Case 1.	Postherpetic neuralgia ophthalmic branch of trigeminal.	Mesencephalic tractotomy.	Not stated.	Early death.	Postmortem: Softening in temporal lobe.

Table IX

SPINOTHALAMIC TRACTOTOMY IN MESENCEPHALON

	Condition	*Tractotomy*	*Sensory Loss*	*Result*	*Complications*
Walker (1942B)					
Case 1.	Thalamic syndrome.	L. mesencephalic tractotomy with bleeding following incision.	Analgesia of R side of body.	Died in 26 hrs.	Death probably due to injury of brain stem in controlling haemorrhage.
Case 2.	Carcinoma of tongue with cervical metastases.	L mesencephalic tractotomy *	Analgesia of R. side except face and leg at 6 days. Hemihypalgesia at 3 wks	Complete relief to death in 1 mo.	R. homonymous hemianopsia.
Walker (1942C)					
Case 3.	Teratoma of testicle with abdominal and cervical metastases	9/41: R. mesencephalic tractotomy.*	Analgesia of L. side of body for first 3 wks.	Relief to death on 68th day.	L. homonymous hemianopsia (transitory). Paraesthesia of L. side with hyperpathia after 3 wks.
Case 4.	Osteogenic sarcoma of maxilla, recurrent after resection.	1/42. R. mesencephalic tractotomy.*	Left-sided hypalgesia limited to face, arm, and thorax.	Fair relief to death in 6 wks.	Postoperative stupor which gradually cleared. Death from uraemia. Postmortem showed operative injury to occipital lobe.
Case 5.	R. upper arm amputation with painful phantom.	2/42: L mesencephalic tractotomy.	Analgesia of R. side of body. Faded to hypalgesia at 3 mos.	Complete relief at 3 mos	Burning paraesthesia R. side.
Walker (1950)					
Cases 6 to 13.	Not stated.	Mesencephalic tractotomy.	Not stated.	*Results in this and two previous series:* Good: 6; Fair: 3; Poor: 1; Died: 1; Not followed: 2	No serious complications reported in 12 survivors except severe paraesthesia in 10 per cent.
K. G. McKenzie (personal comm)					
Case 1.	Painful shoulder amputation and degenerative arthritis of hip on same side	Mesencephalic tractotomy	Entire contralateral side	Shoulder pain relieved, hip not.	None.

3. Wm. G. MGH U-486526 Age 50	Carcinoma of mouth, tongue, and jaw. Previous ligation lingual artery for haemorrhage.	4/47: L mesencephalic tractotomy.* Bleeding from incision difficult to control.	Impossible to determine.	Impossible to determine.	Postoperative coma and death on 5th day.
4. Samuel G. MGH U-568079 Age 76	Carcinoma of tongue and mandible with cervical metastases (L.).	4/47: R. mesencephalic tractotomy. Brisk bleeding from incision controlled by electrocoagulation.	Unilateral high grade hypalgesia of head and neck, less marked in arm and torso, none in leg.	Pain apparently relieved to death on 5th day.	After operation patient somewhat stuporous with L. hemiparesis. Postmortem: Extensive bronchopneumonia.
5. Jeanette S. MGH U-701367 Age 63	Carcinoma of thyroid with metastases to upper neck.	1/51: L. mesencephalic tractotomy. Electrical lesion with direct current supplemented by mechanical division of fibres.	Analgesia fading to high grade hypalgesia from top of head down to costal margin; after 2 mos. sensation in lower face was normal	Pain relieved 3 mos., then mild recurrence in R. shoulder. Later severe pain in R. thigh. Died at 5 mos.	Temporary R. homonymous hemianopsia, L. medial rectus paresis. Severe sensory aphasia persisted till death.

*Operative note states that vein of Labbé was sacrificed.

TABLE IX

SPINOTHALAMIC TRACTOTOMY IN MESENCEPHALON—(Continued)

	Condition	*Tractotomy*	*Sensory Loss*	*Result*	*Complications*
Case 2.	Painful amputation stump of thumb; cervical posterior rhizotomy with short duration of relief of pain.	Mesencephalic tractotomy.	Complete hemianalgesia lasted only few hours, receding to small sensory loss same as before operation.	Relief of pain at 2 mos.	None.
Sjoqvist (1949)					
Case 1.	Postherpetic neuralgia, R ophthalmic branch of trigeminal.	Mesencephalic tractotomy.	Complete R. hemianalgesia, hemianopsia, hemiplegia, and aphasia.	Impossible to determine. Died on 7th day.	Postmortem: Large intracerebral haematoma posterior part L. temporal lobe.
Case 2	Postherpetic neuralgia, ophthalmic branch of trigeminal.	Mesencephalic tractotomy.	Complete R. hemianalgesia and hemianopsia; later R. hemiplegia and aphasia.	Relief to death 10 days after operation.	Postmortem: Large intracerebral haematoma L. temporal lobe.
Personal Cases					
1. Peter M. MGH U-542015 Age 81	Recurrent carcinoma of lip with cervical and supraclavicular metastases (L.).	12/46: R. mesencephalic tractotomy.*	Unilateral analgesia of head, neck, arm, and thorax with preservation of sensation below.	Complete relief to death in 19 days.	None. Patient's disease progressed rapidly. Postmortem: Bronchopneumonia.
2. Charles R MGH U-568073 Age 62	Recurrent carcinoma of antrum, jaw, and cheek (R.).	4/47: L. mesencephalic tractotomy.*	Unilateral hypalgesia of head, neck, arm, and upper 7 thoracic dermatomes.	Pain apparently relieved, but patient complained of paraesthesia. Died 23rd day.	Postoperative oedema with hemiparesis, aphasia, and right-sided seizures. These signs cleared but patient gradually deteriorated to death. Postmortem: Extensive bronchopneumonia.

has noticed this in only 10 per cent of his cases, but Schwartz (1950) mentions "distressing paraesthesia" in both the patients he operated upon. In addition Norman Dott (personal communication) has described to us a severe case which he has never reported, and K. G. McKenzie (personal communication, 1950) says that "at the start I was rather enthusiastic about the procedure, but we have been so concerned about severe paraesthesias that we are no longer looking for cases to do."

It is therefore our conclusion that spinothalamic tractotomy in the mesencephalon must still be regarded as an experimental procedure. While analgesia or a sufficient degree of hypalgesia can be obtained in a high proportion of cases, the risk of mortality from local oedema of the mesencephalon or temporal lobe and the danger of disagreeable residual paraesthesia are at present too great to justify the operation. Its potential value in the intractable atypical neuralgias of the face and in carcinoma of the pharyngeal region, where the vagus is an important conductor of pain, is so great that continued efforts must be made to overcome these objections. Care in preserving venous drainage from the temporal lobe and the use of radiation to produce the lesions, if they can be accurately made, may reduce postoperative hemianopsia, stupor, and bleeding in the brain stem. Possibly these difficulties may be overcome by refinements in making the lesions with improved stereotactic instruments, but we see no solution to prevent the production of paraesthesia, which may be even more troublesome than the original pain.

I. CONCLUSIONS

From this description of our experience with effecting relief of unbearable pain in malignant disease and other peripheral neuralgias it is evident that surgical interruption of its centripetal pathway in the spinal cord and brain stem is beset by certain difficulties which cannot invariably be overcome. It has nevertheless become our conviction that the operation, at least below the level of the midbrain, can be made a relatively harmless procedure, and capable of achieving a high proportion of successful results in properly selected cases. For these reasons the surgeon should make every effort to perfect his technique and should be on his guard not to ascribe his failures to difficulties inherent in the method. To be successful the operation must be performed at a level high enough to allow for unusually extensive decussation of the pain-conducting fibres. Allowance must also be made for the wide dissemination of these fibres throughout the anterior quadrant of the cord. Equally important, the level of analgesia must be verified at operation.

When these essentials have been fulfilled failures after cordotomy will be few. Unfortunately they will still occur from late falls in the level of

which contain the acoustic fibres, causes only a minimal depression of auditory acuity (reduction in higher tones in the contralateral ear), as the tract on each side carries fibres from both ears. A bilateral section, however, would result in total deafness, as has been observed in a single case reported by Walker.

The three outstanding difficulties with the procedure are the frequent occurrence of disagreeable paraesthesiae in the analgesic or hypalgesic zone, the risk of operative mortality, and the tendency of the analgesia to fade.

The postoperative mortality in Walker's series of 13 cases (1950) has been only 7 per cent; in McKenzie's (personal communication, 1950) six cases, the second largest series, there have been no deaths. Our own mortality is appalling, and both of us may well be held responsible for choosing patients who were too poor operative risks for our first attempts. William G., for example, had required a recent ligation of the lingual artery to control bleeding from an area of massive necrosis in the tongue and jaw, and Dr. Walker himself had declined to do his operation on this man some months before. In these early cases we did not appreciate the risks of coagulating the vein of Labbé, and three of our patients showed definite evidence of cerebral oedema. Guiot (1948) has since called our attention to this danger of sacrificing venous drainage from the base of the temporal lobe, and recommends elevation of the brain more anteriorly in about the plane of the external auditory canal, i.e., anterior to the principal cluster of veins. One of his patients, whom he reported with Forjaz (1947), was found to have extensive softening of the temporal lobe. Walker has written us that, in his opinion, "Dr. Guiot is quite correct in stating that coagulation of the vein of Labbé may be responsible for severe cerebral oedema." In our Cases 3 and 4 there was troublesome bleeding from within the tractotomy incision which necessitated coagulation and considerable trauma to this critical area. Our deaths, added to those reported by David *et al.* (1947), Guiot and Forjaz (1947), and Sjöqvist (1949) raise the operative mortality to 24 per cent in this series of 29 operations.

The second serious complication, residual paraesthesiae in the analgesic area, may also be a major problem. This appeared to be the case in the two chimpanzees, Alice and Johnny, into whose lower mesencephalons Sjöqvist (1949) made incisions aimed at a complete transection of one medial lemniscus. These animals seemed to have complete anaesthesia for all qualities of sensation for about a week. Then a needle prick in these areas caused the animals to scratch violently as if they felt itching. After *this operation patients may complain of a burning sensation, dysaesthesia,* or disagreeable tingling when touched with a pin that is worse than the actual feeling of prick on the opposite side. At times this condition is exaggerated by emotional factors, as is the case so often in causalgia. Walker

CHAPTER X

CEREBRAL OPERATIONS FOR RELIEF OF PAIN*

A. LEUCOTOMY (LOBOTOMY) AND LIMITED LOBECTOMY —SURGICAL CONSIDERATIONS

1. Prefrontal Leucotomy

THE ANTERIOR PORTION of the frontal cortex, areas 9, 10, 11, and 12, as well as areas 13 and 14 of the supraorbital cortex, receive fibre projections from the dorsomedial nucleus of the thalamus, while others from the anterior nucleus run to area 24 in the cingulate gyrus. Interruption of these fibres or resection of the corresponding cortical areas suppresses awareness of suffering, concern over incurable illness, and the reactive expression of pain. These operations do not actually raise the sensory threshold.

An account of how bifrontal leucotomy came to be used for the relief of pain has never appeared in medical literature. In 1936 Watts (Freeman and Watts, 1950, p. 354) leucotomized a woman with severe back pain which had confined her to bed for about two years. This operation was done for a severe psychoneurosis. She was out of bed within a few days and, although she complained of some pain, was still working 15 years later. Actually she was classified as a case of conversion hysteria and it was not until 1943, when Watts performed his first leucotomy for the relief of pain, that he realized the full possibilities of this procedure (personal communication). In the meantime W. P. Van Wagenen in 1941 had carried out the procedure in a patient with pain in a phantom limb following lower quarter amputation (hemipelvectomy) with severe narcotic and alcoholic addiction. Although relieved of his suffering and addiction, this man became such a behaviour problem that he has spent most of the intervening years in a state

*Sections of this chapter were written by Dr. Stanley Cobb, Bullard Professor of Neuropathology, Emeritus, at Harvard Medical School and former Chief of the Psychiatric Service at the Massachusetts General Hospital, and Dr. Frances J. Bonner, Assistant in Psychiatry in both institutions A part has been presented by one of us before the Clinical Congress of the American College of Surgeons in Boston, October 26, 1950, and published in *Surgery, Gynecology and Obstetrics* (White, 1951), and we are indebted to the editor of the Journal for his kind permission to use this material. The psychological findings have been presented before the Association for Research in Nervous and Mental Disease at their meeting in New York on December 15, 1951, and published in the transactions of that society as well as in *Psychosomatic Medicine* (Bonner, Cobb, Sweet, and White, 1952).

analgesia and will be apparent at once if there are unusual anatomical variations in the central pathway of pain, or if the surgeon has been misled by inadequate testing or an over-sedated patient. Difficulty in recognizing the confirmed morphine addict and psychoneurotic will also add a small number of failures, but the sum total of disappointing results should not exceed 30 per cent of the general cases selected for operation and 15 to 20 per cent in the more favourable groups.

No final opinion can yet be given in regard to spinothalamic tractotomy in the medulla and mesencephalon. Tractotomy at the medullary level is more dangerous than upper cervical cordotomy, and one cannot be certain of obtaining a much higher level of permanent analgesia. If the distribution of superficial vessels does not make the medullary incision too difficult, and if it is carefully performed, it should not cause serious complications. We hope that we shall be able to devise a method of making high lesions with accuracy and without undue risk. Until this possibility has been developed, we believe the best policy to pursue in securing a high cervical analgesia is to perform a limited suboccipital craniectomy with laminectomy of the atlas. With this exposure the tractotomy can be performed at a level just caudal to the obex in a favourable case, or at the level of the second cervical root, where pyramidal decussation is complete, if the vascular pattern at the side of the medulla makes the higher incision too difficult. When it is decided to perform the tractotomy at the more caudal level, it is only necessary to remove part of the lamina of the second cervical vertebra.

Exposure and sectioning of the tract in the midbrain have carried an excessive mortality and a high incidence of disagreeable paraesthesias. We consider this operation still too much in the experimental stage to justify general adoption at this date.

While realizing that there have been serious complications and an appreciable number of failures in spite of all our efforts to improve the effectiveness of spinothalamic tractotomy, it is nevertheless our considered opinion that this procedure in properly selected cases is generally preferable to frontal leucotomy. This is at variance with opinions expressed in many recent articles which are summarized in Chapter X. When one stops to contrast the degree of apathy, adverse change in personality, and mental deterioration that so often follow every modification of leucotomy performed for relief of suffering, a preliminary trial of cordotomy is nearly always justified. Leucotomy should be reserved for the small proportion of failures after other procedures have been tried, and for such insoluble problems in the relief of pain as ophthalmic herpes, atypical facial neuralgia, the patient with too high or too widely disseminated malignant disease, and for the cancerous individual suffering from fears of imminent death by exsanguination or strangulation.

by the wife of a patient in whom the operation appears to have been performed for relief of chronic backache:

"That operation was performed on my husband in Sept. 1949 and it has also been a very sad affair, and if the doctor had of spoke of it as you do* we would never of had it done, but he said it would slow him up but he would be able to do the things he always did even be able to get at his place of business, but he can not do anything and do it right, he cant even take care of him self in the bath room, and does not take any interest in anything. When he went into it mentally he was fine kept in contack with his business even done some of the book work, but he had suffered pain for years from back trouble. . . I some days think I will loose my mind going through this with him. I just cant seem to make him do anything it takes him about two hours to get out of the bath room in the A.M. and the same at night. I just have to keep nagging at him or he would be in there all night, so when you put up with this seven days a week you feel as if you have been thru the mill."

Only a few papers have appeared warning against the indiscriminate use of this mutilating type of surgery. Krayenbühl and Stoll (1950A) found that of seven patients after leucotomy and one after topectomy, all who were favourably influenced by the operation manifested personality disorders, and that definite psychical changes were absent only when the pain was not relieved. Relapses tended to occur after a few months, coinciding with readjustment of the personality. These authors therefore concluded that the operation ought to be performed only on patients for whom there is no other hope. Falconer (1948) likewise stated that "the operation of frontal leucotomy for intractable pain will always remain, not a procedure of first choice, but rather one of therapeutic desperation." He cites the discouraged statement of the daughter of one of these unfortunate individuals that illustrates the profound state of apathy and disinterestedness which makes the leucotomized patient so difficult to live with: "It would make no difference to Dad whether I told him that I had won 1000 pounds, or that I was going outside to shoot myself." Consequently, Falconer goes on to say, the surgeon should always first direct his effort at section of the pain-conducting fibres at an appropriate level in either the peripheral or central nervous system; only when these efforts have failed or pain has become a morbid preoccupation causing total invalidism is leucotomy justified.

It has become our working rule never to resort to leucotomy in any condition in which there is at least an even chance of relief by rhizotomy or cordotomy. These are comparatively harmless procedures and should first be given a thorough trial. In the case of unsuccessful cordotomies, with in-

*This letter was received by one of us following the newspaper quotation of a paper discussing the disadvantages of leucotomy which was read at the 1950 meeting of the American College of Surgeons (see White, 1951).

institution and Van Wagenen has never published the case. The first article to recommend the procedure for relief of suffering connected with nonpsychiatric disease was published by Watts and Freeman in 1946.

Following the latter publication this solution to the problem of unbearable pain has had a steadily increasing vogue. In certain painful states, such as post-herpetic and some other atypical facial neuralgias, carcinoma of the oropharynx with pain radiating to the ear, and bilateral malignant disease of the neck and upper chest, no other solution is established. In addition to its legitimate use in these conditions, bilateral frontal leucotomy has been advocated by Freeman and Watts (1948), Hawkes and Gotten (1948), and Hamilton and Hayes (1949) for the relief of pain in abdominal and pelvic cancer, the lightning crises of tabes dorsalis, stump neuralgia, and the pain of phantom limb. In all of these latter conditions specific interruption of sensory fibres has in our hands proven satisfactory in better than three cases out of four (White, Sweet, Hawkins, and Nilges, 1950).

Although frontal leucotomy is an easier operation for the surgeon, it may not be the best treatment for the patient. The risk of operative mortality is somewhat greater than after operation on the cord, though not greater than when the pain pathway has to be cut in the medulla or mesencephalon. The danger of postoperative seizures following cortical scars in the frontal area also outweighs the possible complications from injury to descending spinal pathways. The major problem, however, that confronts the candidate for leucotomy is the psychological deterioration that follows bilateral transection of the frontal lobes. If the incision is made too far posteriorly, the damage is appalling; if sufficient frontal cortex is not disconnected from the thalamus, relief from pain is uncertain. In any event, the price that must be paid in the sacrifice of certain qualities of personality, which occurs in even the modified, more limited forms of leucotomy, and the severe mental deterioration that so often follows bilateral transection in nonpsychotic patients justifies these procedures only in very special circumstances.

It must be borne in mind that after bilateral frontal leucotomy there is almost no chance that the patient will ever be able to be self-supporting again. While this is sometimes possible when the operation has been performed for some psychotic state, we have yet to see in our group of patients the person capable of returning to productive work, even though he no longer complains of any pain.* Some will require institutional care and the majority become a serious burden to their families.

The thoughtlessness with which this procedure has been recommended is really appalling. No words of ours can emphasize the harm that can be done to the patient and his family as effectively as portions of a letter written

*This statement has been corroborated by J. W. Watts at a symposium on pain held at the Academy of Medicine in New York, May 15, 1951.

by the wife of a patient in whom the operation appears to have been performed for relief of chronic backache:

> "That operation was performed on my husband in Sept. 1949 and it has also been a very sad affair, and if the doctor had of spoke of it as you do* we would never of had it done, but he said it would slow him up but he would be able to do the things he always did even be able to get at his place of business, but he can not do anything and do it right, he cant even take care of him self in the bath room, and does not take any interest in anything. When he went into it mentally he was fine kept in contack with his business even done some of the book work, but he had suffered pain for years from back trouble. . . I some days think I will loose my mind going through this with him. I just cant seem to make him do anything it takes him about two hours to get out of the bath room in the A.M. and the same at night. I just have to keep nagging at him or he would be in there all night, so when you put up with this seven days a week you feel as if you have been thru the mill."

Only a few papers have appeared warning against the indiscriminate use of this mutilating type of surgery. Krayenbühl and Stoll (1950A) found that of seven patients after leucotomy and one after topectomy, all who were favourably influenced by the operation manifested personality disorders, and that definite psychical changes were absent only when the pain was not relieved. Relapses tended to occur after a few months, coinciding with readjustment of the personality. These authors therefore concluded that the operation ought to be performed only on patients for whom there is no other hope. Falconer (1948) likewise stated that "the operation of frontal leucotomy for intractable pain will always remain, not a procedure of first choice, but rather one of therapeutic desperation." He cites the discouraged statement of the daughter of one of these unfortunate individuals that illustrates the profound state of apathy and disinterestedness which makes the leucotomized patient so difficult to live with: "It would make no difference to Dad whether I told him that I had won 1000 pounds, or that I was going outside to shoot myself." Consequently, Falconer goes on to say, the surgeon should always first direct his effort at section of the pain-conducting fibres at an appropriate level in either the peripheral or central nervous system; only when these efforts have failed or pain has become a morbid preoccupation causing total invalidism is leucotomy justified.

It has become our working rule never to resort to leucotomy in any condition in which there is at least an even chance of relief by rhizotomy or cordotomy. These are comparatively harmless procedures and should first be given a thorough trial. In the case of unsuccessful cordotomies, with in-

*This letter was received by one of us following the newspaper quotation of a paper discussing the disadvantages of leucotomy which was read at the 1950 meeting of the American College of Surgeons (see White, 1951).

adequate levels of analgesia, we have often made a more complete transection of the anterolateral quadrant. Preliminary substitution of leucotomy is justifiable only in the cases complicated by hopeless addiction to narcotics,* when intractable pain is too diffuse or too high to be treated otherwise, or when no other solution is known. In these circumstances all will agree that the operation is a godsend and that the conservatively leucotomized individual, with all his limitations, is preferable to the chronic morphine addict.

In planning the presentation of this subject it has seemed best to begin with a description of the technical steps of operations on the frontal lobes. We shall then discuss our end results, first in regard to relief of pain and risk of surgical complications. Finally the psychiatric evaluation of these progressively more limited procedures will be presented, followed by a theoretical discussion of the effect of frontal lobe surgery on persistent pain and suffering.

a. Technique of bilateral operation of Freeman and Watts (slightly modified from their description of 1951):—This operation is best carried out under local anaesthesia with the patient in the sitting position on an operating table that can be tilted back in case the blood pressure falls. The plane of transection is just rostral to the frontal horns of the ventricles and the coronal suture, which lies 12 to 13 cm. behind the glabella in the sagittal plane. This first point should be marked on the scalp, and a second superficial to the zygoma 3 cm. behind the lateral rim of the orbit. A third point is marked 5 cm. directly above the second in the coronal plane, as illustrated in Figure 81A. A line connecting points 2 and 3 will pass over the attachment of the sphenoid ridge to the inner table of the skull (pterion) 2½ cm. above the zygoma. The line connecting points 1 and 3 corresponds closely to the coronal suture and marks the anterior tips of the lateral ventricles.

We prefer to centre our trephine openings 1 cm. in front of point 3 (1 cm. in front and above the lower end of the coronal suture) in order to make certain that the leucotome will pass anterior to the tips of the ventricles. This is the extreme posterior limit at which the frontal white matter should be cut for relief of pain, but it lies slightly rostral to the point advocated by Freeman and Watts for psychotic patients. A 1.5 cm. crown trephine is used to remove buttons of bone and a bite of bone is removed from the upper and lower edges of the opening with a rongeur. The dura is next opened crucially. The underlying pial vessels are then coagulated.

*It is only fair to state that it is difficult to tell when narcotic addiction has reached a hopeless stage, because a considerable number of our patients who had been taking morphine derivatives over long periods and in large doses have been able to give this up after an effective cordotomy.

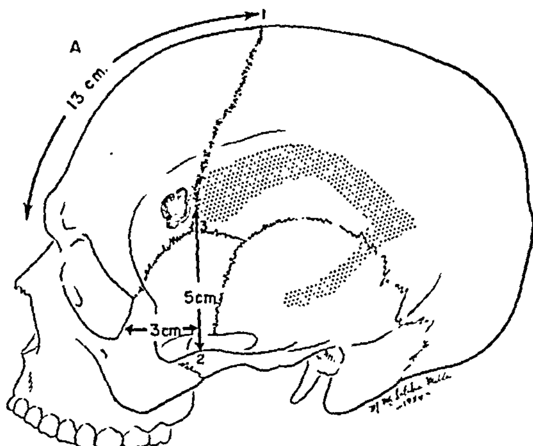
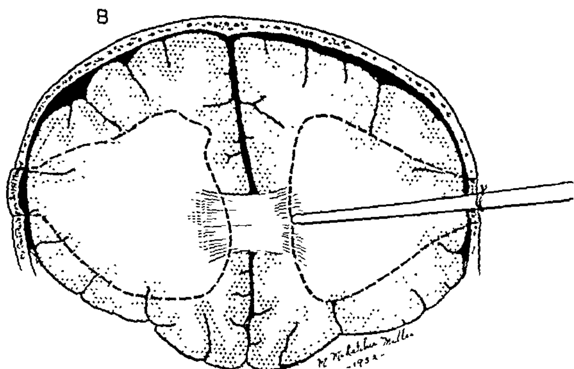


Fig. 81. Bilateral frontal leucotomy of Freeman and Watts.

A. Lateral diagrammatic sketch of skull to illustrate landmarks and leucotome.

B. Anterior-posterior diagrammatic sketch to show extent of insertion of leucotome and area of transection.



Prior to transecting the white matter a ventricular needle should be passed through the proposed line of transection, pointing directly at the opening on the other side, but slightly above this level in order to avoid passing beneath the falx. This is to make sure that the incision will be made anterior to the tip of the ventricle and to ascertain the depth of the falx. The blade of the leucotome is then marked with a silk tie at a point 1 cm.



Fig. 82 Bilateral frontal leucotomy· Cross section of brain in plane of incisions (Patient 3, Table X).

At operation under local anaesthesia the surgeon had intended to cut across the entire frontal white matter on the left side, but deliberately refrained from complete division of the right upper quadrant when changes in the patient's responses indicated an adequate interruption This elderly, arteriosclerotic male with postherpetic neuralgia of intolerable severity died a few hours after operation of myocardial rupture (see page 295).

Note position of anterior cerebral artery, marked A C.

short of this depth, pointing directly at the opening on the other side, which can be aimed at accurately if identified by a metal rod held upright by an assistant. The blade is then manipulated gently, first upwards and slightly backwards, then downwards and forwards in the slightly oblique plane of the coronal suture (Fig. 81B). If definite resistance is encountered, care must be taken not to tear a large blood vessel. This can be avoided by partially withdrawing the blade and sliding it in again just above or below the point of resistance. In this fashion the frontal association fibres can be

cut nearly completely, as shown diagrammatically in Figure 81B and as photographed in the postmortem specimen (Fig. 82). It is important, however, not to bring the blade out through the cortex on the medial side, lest large vessels be torn, particularly the anterior cerebral artery between the cortex and falx. With these precautions haemorrhage is rarely serious. If a large vessel is torn and bleeds persistently, the best solution is to enlarge the trephine openings with a rongeur and widen the incision by suction, so that a lighted retractor can be inserted. The bleeding point can then be located and secured by coagulation.

A similar resection of frontal white matter can be carried out from above under direct vision with suction-coagulation by Lyerly's (1939) technique through parasagittal trephine openings in the coronal suture. This is described below in connection with Scarff's modification of unilateral frontal leucotomy (see section *c*, page 298).

Regardless of whether the lateral or superior approach is used, local anaesthesia will enable the surgeon to judge the proper extent of transection by talking to the patient and continuing the transection until slight euphoria and a definite alteration in responses can be detected. When this state has been reached and haemostasis is complete, the dural edges are loosely approximated, the buttons of bone replaced, and the skin and galea sutured.

Careful nursing is essential for the patient after return to the ward. Changes in blood pressure and pulse rate, as well as a reduction in the level of consciousness, epileptic seizures, and the onset of motor weakness or aphasia may indicate postoperative bleeding and require exploration. It is also important to make sure that the patient does not get out of bed and injure himself before he has become sufficiently oriented, and to care for incontinence of urine and faeces.

Postoperative results: Five of the six patients who have undergone this procedure have suffered no noteworthy surgical complications (Table X). The other, Patient 3, an elderly arteriosclerotic man with postherpetic pain, died of myocardial rupture a few hours after his operation. The five survivors have had satisfactory results in so far as their original pain was concerned and stopped requiring morphine in large amounts. Patient 1, with a hideous facial deformity caused by a rapidly growing retro-orbital chondrosarcoma, illustrated in Figure 83, never complained after leucotomy nor appeared to have any further concern about his disease. Patient 2,* the only sufferer from a lower extremity phantom we have seen who failed to obtain relief after a technically satisfactory cordotomy, subsequently never referred to the pain from which he had suffered so severely following hip disarticula-

*The case history of Patient 2 is given in detail on p. 416.



Fig. 83. Bilateral frontal leucotomy.
Patient 1, Table X. This young man suffered from unremitting severe pain and mental depression over his recurring chondrosarcoma, which had not been relieved by two craniotomies and a subsequent tractotomy of the descending trigeminal root.

tion for chondrosarcoma. After three or four months, when he developed pulmonary metastases, he complained of the new pain and required sedation for this and increasing shortness of breath. Yet even in the terminal month of his life his wife, a highly intelligent school-teacher, was impressed with the effectiveness of small doses of morphine in contrast to the enormous amounts he was consuming with but little benefit prior to leucotomy. In both these men psychological deterioration was severe, although all concerned were grateful for the relief of pain and suffering. In two men whose case histories are summarized in the table there has been prolonged survival. The family of the fifth patient complains that it is nearly impossible to endure him in the home, and the sixth has had to be committed to an institution. We have learned from these last two cases that, even when bilateral leucotomy is performed in two separate stages months apart (after failure of a unilateral operation), the deterioration after the second stage is just as severe and long-lasting as when a bilateral transection is carried out at a single stage. Because of the serious psychological alterations in these individuals, we were forced to regard the bilateral operations as a procedure of last resort and to explore the possible advantages of other less radical modifications.

Table X

BILATERAL FRONTAL LEUCOTOMIES

Patient	*Lesion*	*Area of Pain*	*Relief*	*Duration*	*Postoperative Changes* Immediate (1 Month)	*Postoperative Changes* Later (After 1 Month)
1. Joseph D. MGH U-552387 (with Dr. H. Hamlin)	Recurrent chondrosarcoma of skull and R. orbit.	Orbit, jaw, and ear.	Complete.	2½ mos. to death.	Disorientation, mild paranoia, impaired judgment and insight.	Improved in final month. (See p. 293)
2. Frank I. MGH U-552763 PH	Chondrosarcoma of R. hip. Phantom pain not relieved by cordotomy despite adequate level of analgesia.	Stump and phantom foot.	Pain admitted on questioning, but no longer concerned about it.	5 mos. to death.	Restlessness, confusion and disorientation, delusions, childish.	To death at 5 mos.: childish. (See p. 110)
3. William L. MGH U-635061 PH	Postherpetic neuralgia T3 and T4 of 2 mos. duration. Diabetes and coronary sclerosis.	Upper chest and back.	Pain relieved at moment leucotomy was completed bilaterally.	2 hrs. to sudden postoperative death from myocardial rupture.		
4 Dommc C MGH U-679051	Carcinoma lung with dyspnoea and compression of superior vena cava.	Neck, chest, and abdomen.	No longer aware of pain or his disease.	1 mo. to death.	Impaired judgment, facetious remarks.	
21 Isadore W MGH U-4731	Anaesthesia dolorosa after retrogasserian neurectomy for tic.	Forehead, eye, and cheek.	Freed of pain and morphine addiction.	23 mos.	After second operation: deteriorated, in bed much of day, poor social judgment, picks at nose, impaired judgment.	Same at 23 mos. (See p. 320)
27. Wylie S. MGH U-440170	Bilateral postamputation leg phantoms not relieved by cordotomy with inadequate level of analgesia.	Phantom legs.	Some return of pain.	18 mos.	After second operation: deteriorated, mildly confused, incontinent, masturbates, impaired judgment.	Gradual improvement 8 to 12 mos. after 2nd operation, noted by wife to be at preoperative level except that mind wanders. Relapse at 15 mos. (See p. 321)



Fig. 83. Bilateral frontal leucotomy.
Patient 1, Table X. This young man suffered from unremitting severe pain and mental depression over his recurring chondrosarcoma, which had not been relieved by two craniotomies and a subsequent tractotomy of the descending trigeminal root.

tion for chondrosarcoma. After three or four months, when he developed pulmonary metastases, he complained of the new pain and required sedation for this and increasing shortness of breath. Yet even in the terminal month of his life his wife, a highly intelligent school-teacher, was impressed with the effectiveness of small doses of morphine in contrast to the enormous amounts he was consuming with but little benefit prior to leucotomy. In both these men psychological deterioration was severe, although all concerned were grateful for the relief of pain and suffering. In two men whose case histories are summarized in the table there has been prolonged survival The family of the fifth patient complains that it is nearly impossible to endure him in the home, and the sixth has had to be committed to an institution. We have learned from these last two cases that, even when bilateral leucotomy is performed in two separate stages months apart (after failure of a unilateral operation), the deterioration after the second stage is just as severe and long-lasting as when a bilateral transection is carried out at a single stage. Because of the serious psychological alterations in these individuals, we were forced to regard the bilateral operations as a procedure of last resort and to explore the possible advantages of other less radical modifications.

TABLE XI

BILATERAL LOWER QUADRANT LEUCOTOMIES

Patient	*Lesion*	*Area of Pain*	*Relief*	*Duration*	*Postoperative Changes* Immediate (1 Month)	*Later (After 1 Month)*
5. Patrick R. MGH U-195609	Carcinoma floor of mouth.	Jaw and ear	Good.	3 mos.	Apathetic, incontinent, mildly disoriented, euphoric.	Manageable, talkative, incontinent.
6. Lazaro G. MGH U-516682	Carcinoma tongue.	Jaw and ear, unimproved by previous rhizotomy.	Good.	1 mo. to death.	Apathetic, restless, mild disorientation.	
7. Frank P. MGH U-591201	L. Pancoast syndrome.	L. shoulder and upper chest.	—	1 wk. Operative death.	Coma.	
8. Jacob J. MGH U-591646	Carcinoma tongue.	Throat, ear, and head.	Good	4 wks. to death.	Apathetic.	
9 Wilbur L. MGH U-233175	Fibrosarcoma neck.	Neck and chest.	Good.	1 mo.	Euphoria, loss of initiative and ambition.	
		(2nd operation with section of upper quadrants.)		9 days to death from tracheal compression.	Passive, mildly apathetic.	
10. Thomas B. MGH U-517298	Carcinoma neck and pharynx.	Head and neck.	Good.	6 wks. to death.	Apathetic, uncommunicative except with much prompting.	
11. John K. MGH U-519749	Carcinoma jaw, skull, cervical nodes, lung, and liver.	Bilateral chest.	—	4 days to death.	Insufficient time for evaluation.	
12. Clara H. MGH U-590298	Carcinoma mastoid.	Face, ear, and neck.	Good.	2 mos. to death.	Apathetic, uncommunicative except by nods, incontinent, loss of initiative, mild disorientation.	Improvement at 1 month.
13. Howard L. MGH U-555622	Atypical facial neuralgia.	Burning in face.	Good.	36 mos.	Apathetic, incontinent, mild disorientation and confusion.	Improvement with persistence of apathy, lack of ambition, and initiative, self-inflicted sores (See p. 323)

b. Leucotomy limited to transection of both lower quadrants:—In 1947 and 1948 we attempted to reduce the degree of psychological deterioration by limiting our leucotomies to the lower quadrants of each frontal lobe. There is evidence that the most important frontothalamic connections concerned with emotional integration run from the supraorbital cortex and lie

Fig 84. Bilateral leucotomy limited to inferior quadrants of frontal lobes. X-ray of Patient 10, Table XI. Dural clips mark plane of transection.

in the lower half of the white matter, where they are severed by this partial transection (Fig. 84) (Cobb, 1943; Reitman, 1946).

Postoperative results: This operation has been carried out in nine cases (Table XI). Two patients with advanced carcinoma of the lung and cervical involvement died in coma within the first week. There were no surgical complications in the others. Mental changes, however, appeared to be nearly as severe as if the leucotome had severed the entire frontal white matter on both sides. Patient 13, the only long-term survivor, at 36 months

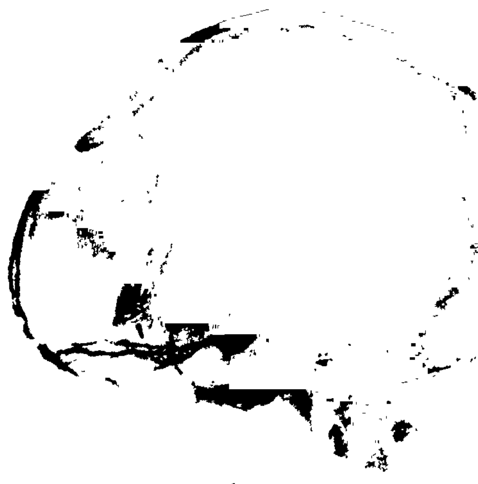


Fig. 86. Unilateral frontal leucotomy.
Extent of transection of white matter depicted by powdered tantalum (Patient 25, Table XII).

remained so indolent and disinterested in his surroundings that he was a severe trial to his family. Although the others were neither incontinent nor serious problems in social behaviour when permitted to associate with other patients on the ward, and although their relief of pain and suffering was satisfactory, we soon lost all enthusiasm for this procedure because of the psychological changes, which will be discussed below.

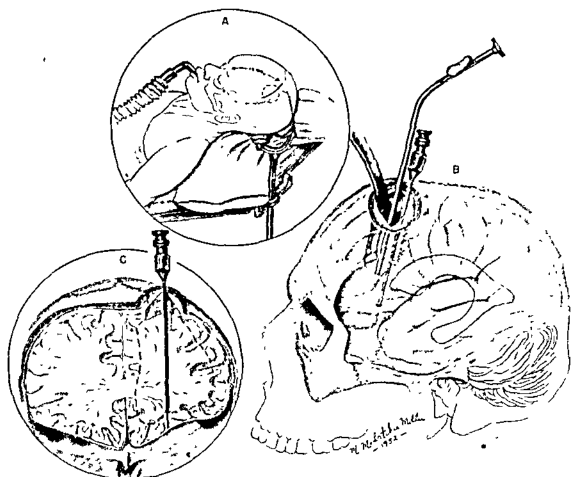


Fig 85. Unilateral frontal leucotomy of Scarff.
A. Position of patient and landmarks for incision
B. Lateral transparent sketch of skull to illustrate operative technique.
C Coronal section to show insertion of ventricle needle anterior to tip of lateral ventricle with its tip against orbital plate anterior to sphenoidal ridge.

c. **Unilateral modification of frontal leucotomy:**—Another modification of frontal leucotomy, which was first proposed by Koskoff *et al.* (1948) and extensively evaluated by Scarff (1948, 1950), consists of complete transection of the frontal white matter on one side just anterior to the tip of the ventricle by complete removal under direct vision. This operation is carried out by the technique described by Lyerly (1939) and Poppen

Table XII

UNILATERAL LEUCOTOMIES

Patient	*Lesion*	*Area of Pain*	*Relief*	*Duration*	*Postoperative Changes* — *Immediate (1 Month)*	*Postoperative Changes* — *Later (After 1 Month)*
14. Myrtis B. MGH U-415609	Metastatic carcinoma, T6 vertebra.	6th intercostal.	Fair.	4 mos.	Confused. Complicating postoperative sepsis and cerebritis.	As mind cleared pain recurred at 1 mos. and she suffered to some extent during remaining 7 mos. of life.
15. Eugenio Z. MGH. U-564904	Carcinoma pharynx.	Face, throat, and neck.	Good.	7 mos. to death.	Apathetic, no initiative.	Slightly apathetic; two episodes of confusion, resumed activities, clubs.
16. John D. MGH U-167727	Carcinoma floor of mouth.	Tongue, jaw, and throat.	Good.	2½ mos. to death.	Apathetic, uncommunicative except by nodding, "tailoring" bathrobe.	Apathetic, uncommunicative except by nodding.
17. Pauline C. MGH U-617042	Atypical thalamic syndrome.	Intense pain in paralyzed arm.	Good.	2 yrs.	Cooperative, friendly. (Prior to psychotherapy and operation was defiant and angry in attitude.)	Defiant and angry in speech at times but without appropriate affect-smiling. (See p. 323) End result, on the whole, was satisfactory to death at 4 yrs.
18. Christine C. MGH U-547776	Carcinoma maxilla.	Ear and neck. Unimproved by trigeminal and glossopharyngeal neurectomy.	Good.	6 wks. to death.	Affect of depression, content of speech not depressed, annoyed by small details, not the case preoperatively.	Remained free of pain and had brief return of limited activity.
19 Edward C. MGH U-642549	Carcinoma tonsil	Throat and mandible.	Good.	4 wks. to death.	Speech less spontaneous, "dumb feeling", impaired abstract thinking, loss of interest in lifetime hobby.	
20. Anna T. MGH U-272589	Carcinoma antrum and ethmoid	Throat and ear. Unimproved by retrogasserian neurectomy.	Good.	6 wks.	Temporary (7-day) loss of ability to speak, apathetic, loss of interest in family and surroundings.	
21. Isadore W. MGH U-4731	Anaesthesia dolorosa after retrogasserian neurectomy for tic.	Forehead, eye, and cheek.	Good.	6 mos.	Apathetic, ate poorly.	Return of pain. Second operation done. (See Table X and p. 320)

(1948). The patient is operated upon in the supine position with the head of the table elevated 30 degrees. As the extent of transection is not based on alterations in the patient's responses, it is most convenient to use ether anaesthesia administered by an intratracheal tube. Scarff has advocated making the incision on the side of the pain or, when this is bilateral, on the side of the dominant hemisphere. As far as we can see, it makes no difference on which side the incision is made. A 7 cm. coronal incision is made extending laterally from the midline 12 cm. behind the glabella, and a 3 cm. button of bone is removed by trephine (Fig. 85A). This is centred 1 cm. in front of the coronal suture and with its medial edge just off the midline. After the dura has been opened the pial vessels are coagulated to permit making a 3 cm. transverse incision in the cortex. Prior to the leucotomy the anterior tip of the ventricle must be located. To do this a ventricular needle is inserted in the parasagittal plane on a bearing pointing a finger's breadth behind the lateral rim of the orbit. It will usually pass just anterior to the ventricle and make contact with the bony floor of the anterior fossa just in front of the lesser wing of the sphenoid. It is best to manipulate the needle until ventricular fluid is obtained and then shift it to a slightly anterior position. The transection is made by suction in the plane of the needle (Fig. 85B&C), picking up and coagulating the major vessels as they are encountered. The incision is extended until buds of grey cortex are visible over its entire periphery. We have then marked the plane of transection by strips of Gelfoam soaked in Pantopaque or by a fine dusting with tantalum powder, so that its extent and position can be checked subsequently by x-ray (Fig. 86). In order to obtain effective results by a unilateral leucotomy the incision must cut across the entire bundle of white matter just in front of the ventricle, so that all fibres connecting the frontal pole with the thalamus are interrupted. After the completion of the leucotomy any oozing surfaces are covered with gelatin foam. The dura is then closed, the button of bone is replaced, and the galea and scalp sutured.

Postoperative results: Nineteen patients have been submitted to this procedure on the side of the dominant hemisphere (Table XII).* Of these, 14 suffered from advanced malignant disease and five others from various neuralgias not due to a fatal condition. The only serious postoperative complication was a staphylococcus cerebritis and meningitis in Patient 14. This fortunately responded well to antibiotic therapy, and her residual aphasia gradually cleared. Another patient, No. 29, developed postoperative seizures, which were controlled effectively by anticonvulsant medication over her brief period of survival. The early results, as far as relief from pain and

*There is no reason to suppose that there would have been any appreciable difference had the unilateral leucotomy been performed on the opposite side, as it is the amount of frontal lobe tissue which ceases to function, more than its exact location, which seems to matter.

28. George F. MGH U-695777	Carcinoma soft palate with metastases.	Constant severe pain in palate, throat, and neck; suicidal depression.	Good.	4 wks to death.	More spontaneous in speech; apathetic and passive.	Denied pain on direct questioning and seemed unconcerned over possibility of imminent death from strangulation or haemorrhage.
29. Ruth C. MGH U-701267	Advanced carcinoma uterine cervix with bladder and renal involvement.	Bilateral high abdominal pain and severe mental depression.	Good.	22 days to death.	Less spontaneous in speech; childish and dirty. Right-sided seizures controlled by Dilantin.	
30. Joseph D. MGH U-678132	Carcinoma of palate.	Mouth, neck, back, and legs, with dysphagia	Fair.	6 mos. to death.	Apathetic, little spontaneous speech, nods head to questions.	Discharged to State Hospital, where he is reported to have improved.
31. Mary H. MGH U-672827	Carcinoma pancreas with vertebral metastases.	Bilateral in abdomen and upper back.	Good.	16 days to death from intestinal obstruction.	No evaluation.	
32. Roy P. MGH U-712153	Melanotic sarcoma of thoracic outlet.	Upper chest and arm with fear of imminent strangulation.	Good.	5 wks. to death.	Mildly euphoric, facetious in speech, swears, contrary in behaviour at times.	Denied pain on direct questioning and was cheerful to time of death by tracheal compression. (See p. 315)

TABLE XII

UNILATERAL LEUCOTOMIES—Continued

Patient	*Lesion*	*Area of Pain*	*Relief*	*Duration*	*Postoperative Changes* — *Immediate (1 Month)*	*Postoperative Changes* — *Later (After 1 Month)*
22. Helen R. MGH U-678606	Carcinoma breast with bony metastases.	Intercostal neuralgia, bilateral.	Good.	4 mos. to death.	Decrease in spontaneous speech, flattening and dissociation of affect.	Observed in hospital over last weeks of life. Remained free of suffering and anxiety. (See p. 304)
23. Sara B. MGH U-678606	Arachnoiditis.	Perineum and both legs.	Fair.	22 mos.	Decreased spontaneous speech, "not right in head"; lack of any feelings, "impossible to please or displease."	At 3 mos. slight return of affect. At 22 mos. increased return of affect, sits unoccupied, loss of ambition and interest. Pain at 26 mos. as bad as before operation (See p. 324)
24. Christine H. MGH U-274289	Post-sympathectomy neuralgia.	L. upper neck and occiput. (Relief of similar neuralgia on R. by previous section of spinothalamic tract in medulla.)	Fair.	19 mos.	Flattening of affect, restlessness; inability to express self in writing; intermittent inability to verbalize thoughts, to grasp symbolic meaning of words, to synthesize thoughts into meaningful wholes; slowed motor performance.	Improvement in all categories with residual: Slight flattening of affect, restlessness, slowed motor performance (twice preoperative level), inability to perform two jobs simultaneously. Required second high cervical cordotomy (see pp. 219, 270, 325, 420, 423).
25. George W. MGH U-287038	Carcinoma jaw.	Mouth, throat, and neck.	Good.	3 wks. to death from carelessness (fire).	Less spontaneous in speech; mildly euphoric; tendency to joke; mild confusion.	
26. Peter F. MGH U-130295	Carcinoma lung.	L. chest, shoulder, and arm.	Fair.	3 wks.	Aphasic. No evaluation.	
27. Wylie S. MGH U-440170	Bilateral postamputation leg phantoms unrelieved by cordotomy with inadequate level of analgesia.	Phantom legs.	Very satisfactory.	2 mos.	Uncommunicative for 2 days; later, difficulty thinking and remembering, loss of ambition; paranoid.	Second operation. (See Table X and p. 321)

of her chest wall nor of underlying pulmonary, bony, or spinal metastases. Owing to the high bilateral distribution of the pain and the patient's dependence on narcotic drugs, leucotomy was the only suitable procedure. This was carried out on the right (dominant) side on November 2, 1949, and she was up the next day. There was no incontinence and only a slight psychical change. She asked for codeine on a few occasions, but all who saw her felt that she was remarkably improved.

Five weeks later Dr. J. W. Cass, her physician, reported that she no longer complained of her left-sided pain, but mentioned the right side at times. She was taking only aspirin and a single codeine tablet at night.

Three months after operation she was readmitted to the hospital for terminal care. She was then extremely emaciated, but was still relatively free from pain and felt that the result of operation had been excellent. She was quite reconciled to the approach of death with minimal suffering. When interviewed by the psychiatrist she seemed coherent and fairly well oriented. She did not once cry, as she had so frequently done before operation when her disease was discussed, although she hated being an invalid on her family's hands; her wish was to go to sleep and not awaken, to have an early release by death.

Patient 32. Roy P., MGH U-712153, 26, a Naval veteran, developed a rapidly spreading malignant melanoma. It arose from a pigmented mole on his right shoulder irritated by his suspenders. The mole had been fulgurated and a rapidly developing axillary node locally excised by his physician. He first entered the Massachusetts General Hospital in August, 1950, where radical supraclavicular and axillary dissections were performed too late. On transfer to the neurosurgical service he had massive tumour in his right upper chest and supraclavicular region, with oedema of the face and arm from superior vena caval obstruction (Fig. 87). There were in addition rapidly increasing pleural effusion, paralysis of the phrenic, vagus, and superior cervical sympathetic trunks, and compression of the trachea and oesophagus. Pain was so intense that it was not adequately controlled by large doses of Demerol by the clock. To make matters worse, he was in terror of imminent death from asphyxia.

A left frontal leucotomy, performed on December 8, 1950, gave him release from pain and all worry concerned with his condition. He was no longer aware of the fatal implications of his disease. Psychological deterioration, however, was pronounced. He was somewhat disoriented and answered simple mathematical and historical questions by the first answer that came into his head. He persisted in picking at the thin skin over the indurated supraclavicular mass and, when this broke down, began to eat the crusts. Nevertheless, both his family and the ward staff felt that the operative relief was a godsend, as he required no further narcotics and remained very cheerful up to his death five weeks later from his disease

Postmortem examination showed massive tumour extending from the supraclavicular region down into the apex of the chest with pleural metas-

suffering are concerned, have been just as good as with the bilateral operations, but when the patients have survived for longer than six or seven months the pain has returned in four out of five. The solitary exception, Patient 17, remained remarkably cheerful and uncomplaining after two years, although prior to operation this woman suffered unbearable burning left-sided pain following an embolism of the right middle cerebral artery. Prior to the left-sided leucotomy she was so sullen and resentful that it had been impossible to help her. Fourteen months after her unilateral leucotomy she almost died from pelvic peritonitis, the symptoms of which she had neglected for six days. In relation to this woman's utter disregard of symptoms of spreading pelvic peritonitis, which nearly caused her death, the postoperative carelessness of Patient 25 led to a very tragic accident. Shortly after discharge he attempted to fill a fuel tank while he was smoking and burned himself to death.

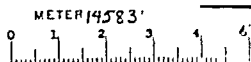
Wide experience with advanced malignant disease in which pain is a major problem has taught us that relatively few patients who cannot be relieved by anterolateral cordotomy or rhizotomy are likely to survive for more than six months. Of this group of 14 only one (Patient 14) outlived the period in which relative comfort can be obtained from a unilateral frontal transection. This woman with an upper thoracic vertebral metastasis had a return of pain to nearly its original intensity at eight months. On the other hand, as pointed out above, there is little hope of securing permanent relief in the neuralgias in which there is no underlying fatal disease.

Contrary to Scarff's opinion, careful psychiatric examination of our patients, which will be discussed in detail below, has invariably brought out definite postoperative abnormalities. Even though these are generally slight, the patient is likely to be relieved of his pain and mental anguish only as long as they persist. With the exception of Patient 17, there appears to have been a return of pain whenever psychological recovery became nearly complete.

A number of these sufferers from advanced malignant conditions admitted no pain even on direct questioning and showed no concern over death, which they realized was close at hand (cf. Patient 22) or even any fear of imminent strangulation (cf. Patient 32). These fortunate results are brought out in the following case histories:

Patient 22. Mrs. Helen R., MGH U-678606BM, 63, had enjoyed good health until she developed axillary neuralgia in 1946. Thirteen months later examination showed mammary carcinoma and she had a right radical mastectomy. This operation and subsequent radiation had no effect on her pain. She continued to suffer increasing discomfort in her right chest wall and then in the left as well. To control this pain required 100 mgm. doses of Demerol up to five times a day. There was no objective evidence of malignant invasion







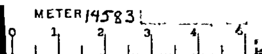


Fig 88. Unilateral frontal leucotomy.

Brain in case of Patient 32, Table XII. This unilateral transection of the frontal white matter had relieved all pain and fear of imminent death over the five terminal weeks of his illness. Posterior and anterior surfaces of block cut through tips of lateral ventricles.

tases and effusion. The tumour compressed his trachea and the neurovascular structures at the thoracic apex. There were additional metastases to the mesenteric nodes and right adrenal, but none to the liver or brain. Coronal cross sections of the frontal lobes are shown in Figure 88 to demonstrate the extent of leucotomy.

Although pain is usually relieved for a period up to six months, it is likely to recur when survival exceeds this period. This was unfortunately true in Patients 14, 21, and 23.



Fig. 87. Unilateral frontal leucotomy.

Melanotic sarcoma of supraclavicular fossa causing Pancoast's syndrome with compression of innominate vein and unbearable pain The patient (No 32, Table XII) was relieved of his pain and fear of imminent strangulation. Death from tracheal compression came without suffering after five weeks

From the data just presented it is clear that unilateral frontal leucotomy is always preferable to a bilateral operation if the individual is unlikely to survive for more than a few months. Under these circumstances he may not have time to recover from the early phase of severe apathy, incontinence, and asocial behaviour, which is so distressing to the relatives during the first month or two after the bilateral operation in nonpsychotic patients. After unilateral leucotomy these severe psychological changes are rare. If pain returns the operation can still be performed on the second side, although at the price of serious psychological deterioration, at least in the early months. These features, together with the greater psychological impairment that we have observed when leucotomy is performed for pain rather than for psychotic states, will be brought out in the final part of this chapter, which concerns the psychiatric evaluation of these operations.

to test his apparatus on the brain of an experimental animal.* The electrode can be withdrawn 1 cm. for a second application of the current if it is desired to produce a large lesion in the lower quadrant. Furthermore, the needles can be reinserted at later dates on one or more occasions to produce more complete transection of the medial quadrants until the desired relief of pain has been achieved, with a minimal sacrifice of frontothalamic association fibres. The fact that the lesions are virtually confined to white matter is perhaps responsible for the absence of postoperative epilepsy in this series.

Grantham's results in his 21 surviving patients are as follows: In two patients the operation has been performed in three stages, in nine others in two, several weeks being allowed to elapse between coagulations for careful observation of the result. In two cases the procedure failed and a second coagulation was refused. Fourteen patients, without obvious personality changes, either denied the presence of pain or no longer had any spontaneous complaints. Two, after triple coagulations, suffered personality changes, but not of such a degree as to detract from the good result. Three others were relieved of their severe pain but still complained of some discomfort. Length of follow-up is not given in this preliminary report, but one of the good features of this procedure is that the limited coagulation of white matter can always be extended if necessary.

The following case summary will serve to bring out the value of limited paramedian destruction of frontal white matter in stages:

Mary H., MGH U-753019BM, 17, was referred to one of us by Dr. Frank Mayfield of Cincinnati for a high cervical cordotomy. Two years before she had suffered a mild sprain of her right index finger playing basketball. From this apparently trivial injury there resulted one of the most severe spreading neuralgias the authors have ever observed. Pain first involved the right fingers and hand, then spread up the forearm and arm. From this she had become totally incapacitated, because even when she carried the arm wrapped in cotton she feared the lightest contact of her skin with other persons or objects. It had become impossible for her even to leave the house. The wrist and arm had become atrophic from disuse, elbow and even shoulder movements almost impossible because of severe pain. Recently her neck had become involved as well, so that she kept her head rotated to the left and had developed a pressure sore on that ear. Despite failure to obtain relief by stellate block, a sympathectomy was done in desperation, but had

*It has been pointed out on p 225 that all electrolytic lesions are subject to wide degrees of variation. This indeed may be so great that the method is dangerous to use in vital areas such as the medulla or mesencephalon This objection, however, does not apply to the frontal white matter, provided serial applications of current are made and the degree of destruction controlled by careful observation of the patient.

d. Bimedial modification of frontal leucotomy:—There is evidence that a bilateral leucotomy, limited to the medial half of the frontal white matter causes much less psychological damage than the more extensive transverse sections; also that it is very effective in the psychotic patients (Levine, Greenblatt, and Solomon, 1951). Poppen (personal communication, 1952) has also been using this operation in the treatment of pain. While he has not yet collected his results, his present impression is that many of these patients are securing relief without paying the price of an undesirable mental deficit. Grantham (1951) has also found that this procedure relieves pain. In order to produce a destructive lesion with minimal damage to the cortex and one that can be enlarged in stages to the desired extent, he has developed a method of electrocoagulation by means of two small needle electrodes, insulated except at their tips. While we have had no personal experience with this method to date, the results in one of our patients so treated by Dr. Frank Mayfield have been of such promise that a brief summary of Grantham's procedure must be included, together with his preliminary statistics and a report of Mayfield and White's remarkable case.

Grantham's technique is as follows: Under local or general anaesthesia bilateral burr holes are made 6 cm. above the glabella, 1.5 to 2 cm. from the midline, and cruciate openings made in the dura. The frontal poles of the lateral ventricles are then located by tapping, 10 cc. of fluid withdrawn and replaced by a similar amount of air or oxygen. Tracks for the electrodes are then made by inserting ventricular needles 1 cm. rostral to the tips of the ventricles, exactly parallel to each other and to the plane of the falx. The proper transverse plane of insertion will usually lie in a line drawn on the scalp to a mark 2 cm. behind the lateral rim of the orbit. One needle is passed until it touches the floor of the anterior fossa, usually at a depth of 7 to 8 cm. Both are then withdrawn and replaced by the coagulating electrodes,* which are inserted to a point 2 cm. above the orbital plate. The depth of the needles and their relation to the tips of the ventricles are checked by x-rays taken in the anteroposterior and lateral projections. For coagulation Grantham advocates use of the Davis-Bovie automatic-gap electrosurgical apparatus with a power setting of 20 on the coagulation device and a 30-second application of current. The heat generated can be tested by grasping one of the dural flaps in a smooth-tipped forceps and applying the current, which should produce charring within three seconds. In 30 seconds this amount of current should produce an area of necrosis about 12 mm. in length by 8 mm. in diameter, but it is advisable for each operator

---

*Needle electrodes are made by the Liebel-Flarsheim Company of Cincinnati, Ohio.

to kill the patient occurred in only one of the 23 cases they report.* An advantage of this manoeuvre is the prompt recovery so that the patients can leave the hospital within a day or two, in the absence of complications. Marked changes in personality are seldom, if ever, seen, according to its proponents. More recently, in an effort to avoid complications, the authors have omitted the lateral sweeps of the leucotome and made only a deep, relatively medial frontal cut.

Of their 23 patients, two were listed as operative deaths, one from "suffocation," the other from intracranial bleeding. Within three months or less 11 more died, and of these three failed to maintain early relief of pain. The proponents of the operation state that their failures probably would have been increased if more of the patients had survived a longer time. They state that 10 of their patients were so weak that it was improbable that they could have survived cordotomy or craniotomy, and they urge their tactic especially for the extremely debilitated victims of cancer. They have also used it in patients with thalamic pain, spastic colitis, tabes, and arachnoiditis. With the exception of thalamic pain, we believe that none of these conditions justifies any form of leucotomy as the initial neurosurgical procedure because, as shown elsewhere in this book, less mutilating operations give such a high proportion of gratifying results. In the light of the high frequency of recurrence of pain in those who survived longer than three months, this operation would appear to be worthy of consideration at best only in patients with the gloomy prognosis of death within this time. Watts and Murphy (1949) have also been disappointed in the relief obtained by the transorbital operation, especially when the pain was of long standing.

2. Unilateral and Bilateral Excision of Orbital or of Temporal Cortex (Table XIII)

We have hoped that it might be possible to remove a cortical area concerned with pain at the price of little or no undesirable mental sequel. Our nebulous basis for selecting the orbital cortex for this removal was as follows: It has been repeatedly shown that the posterior part of this cortex is a principal projection area of the autonomic system. Bailey and Bremer's (1938) finding of a representation of the vagus nerve in the posterior orbital cortex of the cat led Bailey and Sweet (1940) to the precise small area whose stimulation causes arrest of respiration and change in blood pressure and gastric motility in the cat and monkey. Chapman *et al.* (1950) have confirmed the respiratory and vasopressor changes in man and delineated areas from which they may be obtained. Furthermore, bilateral removal of the posterior orbital gyri in macaque monkeys causes alterations in gastric secre-

*We have, however, seen two patients with serious complications of this sort from operations carried out by surgeons at other hospitals, sent to us in a moribund condition.

no effect on her pain. Both in Cincinnati and here thorough psychological investigation showed no evidence of functional overlay.

In the hope that high cervical cordotomy would eliminate all painful impulses coming from the original area of injury, this was carried out on 2/13/52 between the first and second cervical segments. This operation resulted in analgesia through the sixth cervical dermatome without any complication. She was then able to use her hand and forearm freely, but pain on movement of the shoulder, neck, and occiput, as well as acute hyperpathia when this skin was touched, persisted. In addition pain gradually spread to involve her face and then corresponding areas on the opposite side.

Because of these complaints and threatened narcotic addiction, Dr. Frank Mayfield electrocoagulated the lower medial portion of the white matter in both frontal lobes. After the first limited coagulation on 7/3/52 she was somewhat improved, but soon began to regress again. On 7/28 the coagulation was repeated and extended a little. Following this the patient was quite happy and pleasant and engaged in such activities as writing the social column in a neighbourhood newspaper, but she continued to complain of some pain. Therefore a third insertion of the electrodes and further coagulation were carried out on 9/4/52, and she was discharged four days later. Since then for six months she has remained free from pain. At first there was some residual soreness in the neck when she tried to straighten it to overcome the partial ankylosis from prolonged torticollis, but with time this has cleared and she now has a normal range of movement. Even on direct questioning she denies any discomfort. Her personal appearance and interest in being well dressed have greatly improved, as has her interest in all that takes place in her home, driving a car, and completing her education, given up two years ago. Her only handicap is that her appetite has increased and she has tended to gain weight.

Of course, as we have reiterated so many times, this is too soon to evaluate the result of any operation for the relief of pain, but one of the best features of Grantham's modification of leucotomy is that it can easily be extended and the destruction of white matter kept at the minimal extent that will prove effective.

e. **Transorbital leucotomy:**—Williams and Freeman (1951) report the results of their technique for accomplishing with maximal simplicity a division of some of the fibres in the frontal lobes. In this, "the ice-pick operation," the point of the "transorbital leucotome" is inserted into the superior conjunctival sac after the upper eyelid has been pulled forward away from the eyeball. One then drives the shaft of the metal blade through the roof of the orbit into the frontal lobe, eventually for a total of 7 cm. from the margin of the upper eyelid. Directions for manipulating the instrument so as to achieve a modicum of uniformity in the cut are given in some detail by the authors. Surprisingly enough, intracranial haemorrhage sufficient

37. Joseph T. MGH U-582342 Age 63	Postherpetic neuralgia.	L. orbital and frontal regions.	1/6/48. L. orbital gyrectomy	Complained less spontaneously at first; on questioning stated pain worse. Required no medication, then gradual relapse to previous level.	2½ yrs.	For the first 6 wks. marked apathy, spent most of his time in bed, then period of extreme restlessness.	Temporary depression. Improvement in behaviour, but accompanied by increase in complaint of pain, loss of interest in family, friends, and any form of activity.
			6/20/50. R. orbital gyrectomy	No spontaneous complaint, on questioning "pain not bad."	28 mos.	More sociable and friendly, interested in doing carpentry work for first time in 15 yrs.	Following removal of bone flaps for osteomyelitis 10/51, had fluctuating disorientation for person, place, and time, delusions of grandeur; impairment of recent memory.
38. Florence B. MGH U-637368 Age 37	Naevocarcinoma with exenteration of R. eye. C.V.A. causing "thalamic pain", L. side.	R. head, face, and neck, L. torso and limbs.	3/27/51. L. orbital gyrectomy.	Partial relief for 4 mos. Return to original level in 5 mos.	8 mos.	Loss of ambition and pep, difficulty in recent memory.	Slight improvement.
			12/10/51: R. orbital gyrectomy	At first none, later complete	20 mos	Increase in impairment of memory and loss of ambition and pep.	Considerable improvement in memory and energy.
39. Assunta D. MGH U-494 Age 42	C.V.A. causing "thalamic pain."	L. half of head, torso, and limbs.	10/10/51: L. orbital gyrectomy.	None	2 mos.	No change noted.	
			12/31/51: R. orbital gyrectomy.	None for 3½ mos. while in hospital; from 4th mo. no complaint of pain unless asked directly.	9 mos.	Beginning 12 days postop. a 2½ wk period of extreme restlessness, nausea, vomiting, and mental confusion.	During 2nd and 3rd mos. postop. 3 24-hr. periods of hallucination and mental confusion. From 4th mo cheerful and helping other patients in nursing home

TABLE XIII

REMOVAL OF ORBITAL OR TEMPORAL CORTEX

Patient	*Lesion*	*Area of Pain*	*Operation*	*Relief*	*Duration of Follow-up*	*Result*	
						Immediate (1 Month)	*Later (After 1 Month)*
Orbital (8 cases)							
33. Erminia T. MGH U-442564 Age 59	Atypical facial neuralgia, cause unknown, unrelieved by trigeminal rhizotomy.	L. face, chiefly eye and lower jaw.	10/7/47· L. orbital gyrectomy	None.	8 mos	Apathetic for 3 wks, then return to previous state No change in Wechsler-Bellevue test results.	
			8/3/48: R frontal craniotomy without gyrectomy.	Pain stopped for 16 days, then returned in original severity.	4 yrs.	No change in psychological spheres.	10/52: Pain unchanged but patient remains active.
34. Ernest A. MGH U-559278 Age 64	Carcinoma tongue with extension (bilateral) to neck.	R. base of tongue, neck, jaw and side of head.	11/26/47. R orbital gyrectomy.	Largely relieved but returned to preoperative intensity in R. *frontal region.*	5 mos. to death.	Irritable; threatened to strike wife; refused Wechsler-Bellevue testing, many behavioural aberrations, put trousers on backwards, shoe on wrong foot, etc.; general gross deterioration; wandered about with genitalia exposed.	Little improvement.
35. James T. MGH U-721386 Age 32	Traumatic total transverse lesion upper thoracic spinal cord.	Throughout lower limbs.	6/5/51: L. orbital gyrectomy.	Some complaint of original pain but required no medication.	2 mos. to death from frontal lobe abscess.	Slight memory loss for details.	
36. Evelyn P. MGH U-295271 Age 46	Anaesthesia dolorosa following trigeminal rhizotomy *for* tic.	R. face.	1/2/52: R. orbital gyrectomy.	No relief.	10 mos.	No change in mental state.	Same.

37. Joseph T. MGH U-582342 Age 63	Postherpetic neuralgia	L. orbital and frontal regions.	1/6/48: L. orbital gyrectomy.	Complained less spontaneously at first; on questioning stated pain worse. Required no medication, then gradual relapse to previous level.	2½ yrs.	For the first 6 wks. marked apathy, spent most of his time in bed, then period of extreme restlessness.	Temporary depression. Improvement in behaviour, but accompanied by increase in complaint of pain, loss of interest in family, friends, and any form of activity.
			6/20/50 R. orbital gyrectomy	No spontaneous complaint, on questioning "pain not bad."	28 mos.	More sociable and friendly, interested in doing carpentry work for first time in 48 yrs.	Following removal of bone flaps for osteomyelitis 10/51, had fluctuating disorientation for person, place, and time; delusions of grandeur; impairment of recent memory.
38. Florence B. MGH U-637368 Age 37	Naevocarcinoma with exenteration of R. eye. C.V.A. causing "thalamic pain", L. side.	R. head, face, and neck, L. torso and limbs.	3/27/51. L. orbital gyrectomy.	Partial relief for 4 mos. Return to original level in 5 mos.	8 mos.	Loss of ambition and pep; difficulty in recent memory.	Slight improvement.
			12/10/51: R. orbital gyrectomy.	At first none, later complete	20 mos.	Increase in impairment of memory and loss of ambition and pep.	Considerable improvement in memory and energy.
39. Assunta D. MGH U-494 Age 42	C.V.A. causing "thalamic pain."	L. half of head, torso, and limbs.	10/10/51: L. orbital gyrectomy.	None	2 mos.	No change noted.	
			12/31/51: R. orbital gyrectomy.	None for 3½ mos. while in hospital, from 4th mo. no complaint of pain unless asked directly.	9 mos.	Beginning 12 days postop. a 2½ wk. period of extreme restlessness, nausea, vomiting, and mental confusion.	During 2nd and 3rd mos. postop. 3 24-hr. periods of hallucination and mental confusion. From 4th mo cheerful and helping other patients in nursing home.

Table XIII

REMOVAL OF ORBITAL OR TEMPORAL CORTEX—Continued

Patient	*Lesion*	*Area of Pain*	*Operation*	*Relief*	*Duration of Follow-up*	*Result*	
						Immediate (1 Month)	*Later (After 1 Month)*
40. Albina S. MGH U-672523 Age 44	Atypical facial neuralgia, ? post-traumatic, unrelieved by trigeminal rhizotomy.	L face.	12/6/51: L. orbital gyrectomy	No relief.			
			12/10/51: R orbital gyrectomy.	Complete relief.	6 mos. to death.	4 days postop. lapse into coma; no blood clot when wounds re-opened.	From 1 mo. postop. till death status akin to severe Parkinsonism with extreme paucity of voluntary movement all 4 limbs and face plus cogwheel rigidity and resting rhythmic tremor.
Temporal (1 case)							
41. Zelda K MGH U-171879 Age 52	Persistent pain (following total removal acoustic neuroma) unrelieved by L trigeminal rhizotomy and L cervical sympathectomy.	L. face.	2/27/52: L. anterior temporal lobectomy	None.		No change in mental status, but increase in variety of complaints.	
			4/4/52: R. anterior temporal lobectomy.	None.		No change in mental status.	
			5/23/52: L. frontal lobotomy.	? Complete relief.	5 mos.	R. hemiparesis and global aphasia.	Weakness disappeared but apathy and severe aphasia persist.

tion and movement, and a marked vasodilatation in the limbs (Delgado and Livingston, 1948). Ablation of the medial orbital gyrus bilaterally in monkeys leads to a syndrome of aggressiveness and fearlessness considered akin to sham rage. Such findings have made us hope that the orbital gyri are concerned in the emotional component of the response to pain. Fulton (1949) has even surmised that this is the actual cortical projection area for visceral pain. The further conclusions of a number of investigators that severance of inferior frontal fibres was more effective in the treatment of psychosis than division of the superior fibres led us to orbital corticectomy for treatment of pain.

Since autonomic responses are obtained from the posterior orbital cortex, we hypothecated that this area might be important with respect to pain, and that the precise amount of this cortex removed might be pertinent to the problem. Hence we tried in our operative technique to lift out nearly all of the orbital cortex intact as an operative specimen. We hoped thereby to have a precise anatomical check on just what the operation had removed. The excised areas varied greatly in weight, from 11 to 23 grams; the differences appeared to be related mainly to the amount of white matter removed. This method proved to produce more trauma to the brain left behind than if we had completed our removal by gentle suction. In the last two operations we followed the tactic of dividing the white matter just dorsal to the orbital gyri with a lobotomy spatula, and then completing the removal posteriorly with subpial suction which was carried back to the level at which the olfactory tract moves dorsally at a right angle into the brain. Along the line of removal, electrocoagulation was used for any blood vessels. But as we neared the Sylvian fissure posteriorly and the midline medially, we left pia intact and coagulated any vessels several millimeters away from the point at which they were supplying intact brain. By this means we hoped to avoid spreading thrombosis which we thought might have seriously complicated the course of our Patient 40. Figure 89 shows in the insert a typical operative specimen, and the large picture indicates its location on the basal surface of another brain.

Of eight patients we carried out unilateral removal of the orbital cortex in four, and bilateral removal in another four. No protracted useful relief ensued in any of the three long-term survivors with unilateral operation only. In Patient 34 (Ernest A.), whose pain was due to carcinoma, there was serious mental and behavioural deterioration, which did not improve greatly before the patient's death, and, to make matters worse, the original relief of pain was not maintained. The unilateral operation in the other three patients, who had nonlethal disease, produced no significant change in behaviour, but likewise failed to affect the pain in the two patients who survived. In one of these, Patient 33 (Erminia T.), the orbital cortex on



Fig 89. Area of removal in our orbital corticectomies.
In the upper left corner is the specimen of right orbital cortex removed from Joseph T. (Patient 37, Table XIII), a typical sample of the tissue we obtained at these operations. The main illustration shows the relationship of the specimen (within the white dash lines) to the whole brain.

the second side was exposed 10 months after the first operation. Because 15 seconds of stimulation to one area on the orbital surface arrested the respiration for over one minute and was followed by a 15-minute period in which the spontaneous respiratory rate remained around two to five per minute, we decided not to remove the cortex at this time. The wound was closed and, although the pain was completely absent until she returned home, it then recurred promptly. Inasmuch as the pain has not prevented her from carrying out much of her housework and leading an active life for the last four years, we have not performed another operation. Unfor-

tunately the third patient (No. 35, James T.) died abruptly two months after operation from a totally unsuspected inferior frontal abscess at the site of the removal of cortex. *Up until that time his original* pain had been so much reduced that he no longer asked for medication, although preoperatively he had been taking 150 mg. of Demerol every hour and a half.

In the remaining four patients removal of the gyri on the orbital surface was carried out bilaterally in two stages, separated by from four days to two and a half years. The first three of these, Patients 37, 38, and 39, were the most successful cases in the whole discouraging group. In the first, Joseph T., post-herpetic orbito-frontal pain had persisted for two years and had not been relieved by total trigeminal rhizotomy. Removal of the left orbital cortex at first yielded useful partial relief of pain, but this gradually recurred. Removal of the right orbital cortex two and a half years later was followed by nearly complete relief of pain, and for the first time in four and a half years he began to do useful work in his carpentry shop. Nine months later development of osteomyelitis led to removal of his bone flaps, whereupon his mental status worsened abruptly. Gross confusion and disorientation was present for a time, but this largely cleared up. At two and a half years after the second gyrectomy his relief of pain is maintained and he continues to work in his shop. One interesting personality change has occurred in that prior to his cerebral operations he had for years had occasional violent temper tantrums which precipitated domestic crises, but these have been absent since the first gyrectomy and he now has a placid, even disposition.

In Patient 38 (Florence B.) pain referred in particular to the right orbit, and also to the right face, head, and neck, followed exenteration of the orbit for naevocarcinoma in October, 1948 (two and a half years prior to the first gyrectomy). Total right trigeminal rhizotomy in April, 1949, yielded only transitory relief. The problem was made more acute in June, 1949, by a cerebrovascular accident 30 hours after operative reinspection of the middle fossa had disclosed that the earlier rhizotomy was complete. The vascular lesion caused at first a left hemiparesis and left hemianalgesia. Within a few days spontaneous pains came on in the left torso and limbs of the type seen in the thalamic syndrome. Left orbital gyrectomy was finally done in March, 1951. This yielded only transitory partial relief of pain, but some loss of energy and memory has persisted. Orbital gyrectomy on the other side eight and a half months later increased the impairment of energy and memory at first without giving one jot of relief from the pain, but initiative and memory gradually returned, and two years after the second operation she is free of pain and leading a useful life.

Assunta D., Patient 39, had also had a cerebral vascular accident causing pain typical of the thalamic syndrome, which was referred to the entire left side from head to foot. Five and a half years later the performance

of left orbital gyrectomy had no observed effect on her pain, personality, or mentation. Right orbital gyrectomy also failed to alter the pain for the three and a half month additional period in which the patient remained in the hospital. But from the fourth month on, for some unexplained reason, she has stopped complaining of pain spontaneously and cheerfully aids in the care of other patients in the nursing home in which she is staying. Her mental status has returned to its preoperative level.

The final patient in this series, Albina S., had an atypical left facial neuralgia, possibly post-traumatic in origin, which was unrelieved by trigeminal rhizotomy. The orbital gyrectomies were carried out only four days apart. In the early postoperative period there was presumably some spreading thrombosis into the basal ganglia or hypothalamus, because the patient went into coma on her fourth postoperative day after the second procedure. Inspection of the brain at reoperation disclosed no blood clot on either side. The patient gradually emerged from coma and remained in a pitiful static condition from one month after operation until her death six months later. During this time the face was virtually devoid of expressional movements. There was extreme limitation of voluntary movement and pronounced rigidity on passive flexion and extension of all four limbs. Much resting rhythmic tremor made the clinical picture still further resemble that of severe Parkinsonism. Although the patient could speak only a few words and assure us that her pain was relieved, the price was a catastrophic disability and late death.

Complications other than those mentioned above have included the development of a burst of convulsive seizures in one of the eight patients. These have been fully controlled with anticonvulsant drugs. One of the patients (Joseph T.) had periods of apathy alternating with excessive restlessness shortly after returning home following his first gyrectomy. During the active periods he would pace the floor compulsively for hours, giving no explanation of this hyperactivity. Such meaningless actions stopped gradually within three months and did not recur. Another patient (Assunta D.) also had a period of purposeless excessive activity. This came on during the eleventh postoperative day after the second gyrectomy and was so severe that the patient had to be kept under a net for over a week. Behaviour gradually became normal by five weeks after operation. The second gyrectomy in this patient included a total removal of the orbital cortex completed by suction posteriorly.

After these disappointing results we sought to improve a similar patient by bilateral anterior temporal lobectomy in two stages. Zelda K. had continuous left facial pain beginning three months after the total removal of a left acoustic neuroma in August, 1949. Neither left trigeminal rhizotomy nor left superior cervical ganglionectomy influenced the pain. Removal

of the entire anterior portion of the temporal lobe for 3 cm. behind the temporal tip on the left side was followed in five weeks by a more extensive removal extending backwards for 5 cm. on the right side. No defects in the visual fields, no motor or sensory aphasia, and no reduction in an already impaired mental status ensued. But complaints of pain became more vehement and were referred to a wider area. Her preoperative level of intelligence as measured by the Wechsler-Bellevue test revealed a full scale "intelligence quotient" of only 80. In addition, she had evidence of other disease in the basal ganglia in the form of rhythmic tremor and cogwheel rigidity in the left upper limb. The addition of a left frontal lobotomy in the plane extending from the coronal suture to the lesser wing of the sphenoid has reduced the patient to a vegetative state. An initial right hemiparesis and global aphasia have improved, but the patient remains extremely apathetic with speech and comprehension on a primitive level. We should like to point out that the compounding of decorticating procedures (as in this patient) can abruptly produce a mental deficit of tragic degree, especially in a patient such as this one with pre-existing malfunction of the cerebrum and basal ganglia.

Needless to state, we have no intention of carrying out further operations along these lines, in view of the severity of the complications discussed above. However, the relief of pain has persisted in the three surviving patients after bilateral orbital corticectomy, and this encourages us to seek a similar anatomical and therapeutic result by safer methods.

Other more limited operations on the frontal lobes which have not been discussed above are the topectomies of Pool (1951), consisting of bilateral cortical resection of areas 9 and 10, and the cortical undercutting of Scoville (1949) of similar areas by suction and cautery. Adequate data on relief of pain following these procedures are not yet available.

B. OPERATIONS ON THE FRONTAL LOBES—PSYCHOLOGICAL CONSIDERATIONS

The psychiatric service at the Massachusetts General Hospital has taken advantage of this opportunity to study the effects of leucotomy and gyrectomy on individuals with pain but without psychosis. The patients in the first two groups, bilateral leucotomy and bilateral lower quadrant leucotomy, have been seen by psychiatric consultants prior to and following operation. Those in the third and sixth groups, unilateral leucotomy and orbital gyrectomy, have had more extensive work-up, which has included psychiatric consultation pre- and postoperatively with recorded interviews. We have been able to analyze, by means of these interviews, the speech of the patients before and after operation.

Since most of the patients in all groups, except the gyrectomies, have had pain secondary to malignant disease, a long-term follow-up has not been possible. Those patients, however, whose pain was secondary to a nonmalignant lesion have been followed up after operation every month or two whenever possible.

1. Bilateral Frontal Leucotomy

Deterioration in behaviour and impaired judgment seem to be the predominant features in patients following bilateral leucotomy. Masturbation, incontinence, and disorientation, which at times resulted in patients getting in bed with other patients, offered a trying problem to the nurses during hospitalization and to the families during the early periods after discharge. Although there has been gradual improvement in these symptoms with the passage of time, in no instance has the patient improved to the preoperative level. Two cases have been followed for 23 months and 18 months respectively:

Patient 21, Isadore W., MGH U-4731, 58. This junk dealer first entered the hospital with classic tic douloureux in the left ophthalmic division. Following trigeminal tractotomy in the medulla and, later, retrogasserian neurectomy, he again complained of pain, which was now an aching and burning in the left malar region and eye. This anaesthesia dolorosa persisted with increasing intensity. A left frontal leucotomy was performed, following which he was apathetic and ate little, but no longer complained of pain and assumed a cheerful mien. Five months later his atypical neuralgia again became a serious problem to him and his family, so a right frontal leucotomy was performed. The following description given by his daughter summarizes changes following the second operation:

As far as pain was concerned, he was considerably better than he was prior to the operation. He occasionally complained of pain momentarily, but soon forgot about it. He did not require any medication. To counterbalance this, the family felt that his memory was unreliable and that he must therefore be checked up on whenever asked to do anything. A typical example of his behaviour occurred when he was asked to go to the home of one of his daughters one Sunday to take her her dinner. After about half an hour the daughter to whose home he was going called to say that he had not arrived and that she was wondering what had happened. The patient's family then found him standing on his front porch with the dinner in his hands just staring into space. At times when the family told him something he would forget it, but might later say to them that he remembered very well the things he had been told.

The daughter characterized her father as being very stubborn in some ways since the operation. An example of this was that he would be sitting tapping his fingers on a chair and the family would ask him to stop, but he

would persist in doing it. Occasionally when they asked him to do something he would refuse. At other times, however, he would comply with their wishes, even though it might be the same thing he had previously refused to do. It was noted that he picked at things with his hands a great deal since the operation. This included picking at his nose, and on many occasions he did this until it bled, which seemed to happen most often when he picked at the anaesthetic side. His family were frequently annoyed and embarrassed by this. He appeared and complained of being very tired most of the time, and frequently went around the house groaning, complaining of his fatigue, particularly in the morning. If left alone he would sleep until very late in the day, then after getting up would stay up for a few hours and then go back to sleep again. At other times his family would find his behaviour quite amazing. One night before going to bed, and without being told, he went around the house checking all the doors to be sure they were locked. Prior to the operation the patient was quite concerned about money and would frequently ask his son about the five or 10 dollars he owed him, whereas after the operation he never bothered to ask about the money and did not seem to be concerned about its repayment. He was not concerned about his business and never expressed any desire to return to it. The daughter felt that the family were glad of this, as he was a peddler and worked alone and they did not feel that he could be trusted with handling money.

Patient 27, Wylie S., MGH U-410170, 61. This man entered the hospital with a diagnosis of bilateral phantom limbs and pain of six years' duration. Previous anterolateral cordotomies, performed bilaterally in stages, had not produced adequate analgesia and his pain was not relieved (see p. 405).

In connection with the ensuing operations on his frontal lobes, it is of interest to note that prior to the accident which had resulted in the loss of both lower limbs the patient had wandered around from job to job. Following the accident he remained at home, where the situation with his wife became increasingly strained, as he would invite groups of men to the house to drink and play cards. With these bouts of drinking the patient would become "crazy and wild" and, as a result of his behaviour, the wife refused to allow liquor in the house and the men stopped coming to see him. He then became quite sullen and withdrawn, demanding more and more medication and showing strong paranoid tendencies. He remained in bed a large part of the time and was sexually very demanding of his wife On occasional days when he was supposedly in too much pain to get out of bed the wife would come home to find an X drawn on the furnace in the cellar, this being the patient's way of letting her know that he could still get around. On one occasion he threatened her at gunpoint. These periods of difficult behaviour most frequently came after he had been receiving large doses of narcotics, which the patient managed to obtain from the local doctors.

Following a left frontal leucotomy the patient was almost totally uncommunicative during the first two days, although he was conscious and not aphasic. By the seventh postoperative day he could again communicate well,

but found that he had difficulty in thinking and remembering. This gradually improved and later, in describing his immediate postoperative state, he said that he was "in a fog" and that only around the twentieth postoperative day did he seem to be coming out of it. He recalls little of what went on while he was in the "fog" except that he had severe phantom limb pain. On coming out of it he noted that he was "changed" and that he felt low in spirits. He had no ambition at all, the opposite of the way he usually felt. Further questioning revealed that while he was in the fog he felt completely withdrawn and he had the impression that all the doctors and nurses were accusing him of homosexuality and of making homosexual advances to the orderlies. During this period he had a dream in which he was a partner in a homosexual affair.

There was gradual *improvement in the patient's status.* He became able to care for himself, would sit up a fair part of the day and eat his meals with the other patients, and no longer felt that the doctors and nurses were against him. He noted, however, that he did feel "odd" compared to the other patients. As his mental status improved he complained more of pain, eventually noting that it was as bad as prior to the operation.

Following a right leucotomy, two months after the one on the left, the patient's behaviour markedly deteriorated in that he would spend most of his time staring out of the window, was frequently incontinent of urine and faeces, talked circumferentially, was slovenly in his dress, and would masturbate freely.

Because of the deterioration in his behaviour the patient was sent to a state hospital. Here there was a gradual improvement over the next 14 months. A letter from his wife, a nurse, eight months postoperatively reports. "Since you went out [to the state hospital] with me I have been there several times. I stayed at least two and one half hours each visit and I watched everything. *My opinion is that his brain pattern has grown back to practically* what it was before the lobotomies. He can be very charming when he wants to be, and he generally wants to be when I am there, but he also is extremely disagreeable to the orderlies or patients who cross him in any way or annoy him at all. He is not at all sociable, as he speaks to only one man The two sit together and will not speak to anyone except to be sarcastic. He never asks for anything He tells me he still has the original pain and it is no use in telling anyone there, for they would do nothing about it."

A later report from the wife revealed that he seemed to be back to his preoperative personality except that he did not seem to remember things she told him or seem interested in any subject. His attention would wander.

Fifteen months postoperatively the patient had an episode of unconsciousness (etiology unknown) lasting several hours, since which time his behaviour became similar to that immediately after the second operation. He was incontinent, complained of pain in the legs, ate little, had no interests and had little to say to anyone.

2. Bilateral Lower Quadrant Frontal Leucotomy

Marked apathy in each patient, except one, seemed to be the predominant feature of the lower quadrant leucotomies. One patient following the operation was noted to have been euphoric. In addition, incontinence, mild disorientation, uncommunicativeness except by nodding, and decrease in initiative and ambition were noted:

Patient 13, Howard L., MGH U-555622, 68. This patient was followed over a period of 36 months. The following quotation from a letter from his wife summarized the late results seen in this patient: "He sure is a problem. He doesn't do a thing all day but sits in his chair and dozes off a lot. Is like a balky horse, he won't do a thing he doesn't want to. Half the time he won't even put his stockings on and sits and rubs his fingers up and down his ankle. He has a sore on his nose and he picks at that all the time. He told the fellow at the barber shop where he goes he wished he never had it done, but never told us so here at home. I try so hard when the weather is nice to get him to take a walk outside, but he won't."

3. Unilateral Frontal Leucotomy

In general the changes most frequently noted following unilateral leucotomy are a decrease in spontaneous speech and flattening of the affect. In four instances inappropriate affect was noted. Other findings included impaired abstraction and euphoria. In one case (Patient 23) there seemed to be a total lack of affect for three months. In the three cases followed for two years, 22 months, and 19 months respectively there has been a gradual return psychologically towards the preoperative level, though in no instance has the preoperative level been attained.

Patient 17, Pauline C., MGH U-617042, 28. This woman entered the hospital with the chief complaint of severe pain and spasm in the left hand, arm, and shoulder of four months' duration. She had had rheumatic fever since the age of five with multiple emboli, from which she had made a complete recovery until the onset of painful spasm of the left hand and arm.

Prior to her transfer to the psychiatric service she showed a querulous, hostile, angry despair. She was overtly very hostile towards all of the doctors and nurses except one neurosurgeon. She questioned the motives of most of the people who looked after her and was very demanding Following a period of psychotherapy a considerable change was brought about and, although she remained somewhat angry and defiant, her defiance was directed to her disability rather than to those caring for her. She became more cooperative and hopeful and accepted the idea of leucotomy.

A right unilateral leucotomy was performed, following which the patient was cooperative, friendly on the ward, and, while she did not deny that her pain existed and occasionally troubled her, she was not distressed and ap-

peared able to stand the pain. After operation she was up and about, mixed freely with the other patients, and was able to live and sleep without medication.

When seen five months after operation she was free of pain except in the middle phalangeal joints of the fingers of the left hand. She noted that she was irritable and would fly off the handle frequently. She constantly complained that her condition was unbearable. She declared that the orthopaedic surgeons had promised to operate on the hand and that she was going to do something (implying suicide) if the doctors did not hurry and get a bed for her so she could be admitted to the hospital. Although complaining and desperate in her words, her affect was dissociated, and she was very pleasant, smiling, and apparently fairly comfortable.

When last seen two years postoperatively, the patient was totally free of pain and stated subsequently, "I've never felt so good in all my life." Shortly after this she developed peritonitis, which she neglected for six days before entering another hospital, too ill to be operated upon. Nevertheless she recovered and was again relatively well, only to have two further cerebral emboli, the second of which was fatal. Postmortem examination showed a right thalamic and other cerebral infarcts, and the scar of a very complete transection of the frontal white matter on the right side.

Patient 23, Mrs. Sara B., MGH U-487628BM, 59. This woman entered the hospital because of intractable pain in the rectum and both legs of nine years' duration. A series of three laminectomies by other surgeons had failed to reveal any lesion other than an arachnoiditis. A right anterolateral tractotomy resulted in temporary relief of pain, but she had later return of rectal burning.

Prior to the onset of her illness the patient, mother of two children, had been an extremely active person. She described herself as being "constantly on the go." During a routine day she would usually get her housework done in time to go in town for lunch and the movies. At night she and her husband would frequently go visiting or have friends in. During her earlier life she had devoted her time to her home and her children. Following the onset of pain she persisted in her home and extra-home activities and described how, on going into town, the pain would frequently be so severe that she would have to stop wherever she was and sit down until it was relieved. During the past year, because of the intense pain, she had been unable to go out and spent most of her time at home watching television and doing other things that could be done while sitting down. She described her discomfort as a burning sensation in the rectal and vulvar regions and a pulling pain which extended down into the legs.

When seen following a left unilateral leucotomy the patient noted the fact that she was not "right in the head" but could not describe the difficulty further. Her response to practically every question was "I don't know," and one had the impression that actually she did not know how she was feeling or whether or not she had pain. She was able to tell about the visitors she had,

but showed absolutely no feelings or affect about any of the things that had happened. In addition to being apathetic and without interest in anything going on around her, she showed a good deal of restlessness which was characterized by moving her hands in a purposeless fashion, picking at her bandage, or shifting her position.

Following her return home on the tenth postoperative day her husband noted that this state persisted and he found it very disturbing. The patient would spend the entire day just sitting and at night would watch the television without making any comment or expressing any likes or dislikes for the program she was seeing. He noted that it was "impossible to find anything that would please or displease her."

Three months postoperatively her husband noted that the patient had begun to show signs of anger when, for example, she had asked that he bring something home and he had forgotten to do so. He was greatly pleased at this return of affect.

When she was seen again 26 months postoperatively a great increase in affect was noticeable, though not to the preoperative level. With this there had been a return of the pain, which the patient described as being as severe as before operation. She enjoyed visits of friends and family for short periods of time, but spent practically the entire day just sitting and looking out of the window and not engaged in conversation. She complained of not being able to interest herself in anything, particularly when she was alone.

Patient 24, Christine H., MGH U-274289, 26. In 1945 this woman with severe Raynaud's disease in both upper extremities had been treated by bilateral upper thoracic preganglionic sympathectomies through the retropleural approach. On account of recurrent vasospasm sympathetic denervation was repeated three years later by extensive resections of the decentralized stellate ganglia and the areas of retropleural scar at the sides of the second and third thoracic vertebrae. These procedures on the right and left sides were carried out in two stages through the transthoracic route by Dr. R. R. Linton and Dr. F A. Simeone. The patient then began to complain of persistent pain which was unbearably severe in the right upper chest and shoulder. Although this pain was effectively relieved by an anterolateral cordotomy at the first cervical level, she was still incapacitated and addicted to narcotics because of increasing neuralgia on the opposite side. Because of our reluctance to attempt bilateral cordotomy at such a high level it was decided to try a left frontal leucotomy. At the time of hospitalization for leucotomy the residual pain on the left side was very severe, beginning in the fingertips and migrating up the inner aspect of the arm to involve the axilla, shoulder, left chest, and occasionally the left torso and lower limb. Prior to hospitalization she required Demerol twice a day, but failed to respond to any other medication.

Left unilateral leucotomy was carried out, and in the early postoperative period a variety of difficulties with understanding speech and writing were

present. The type of defect which persisted is illustrated by the following episode:

On the tenth postoperative day the patient was due to go home but, because of a slight elevation in temperature, she was forced to remain in the hospital. When seen on this day she expressed a good deal of concern and mild anger about the fact that the doctors would not allow her to go home, but more specifically because they did not tell her the reason she could not go. In discussing this further the patient finally said, "If they're telling the truth [meaning if her temperature was elevated], well, that's all there is to it." Doctor. "Do you feel that they might not be telling the truth?" Patient: "I don't know. I always read the thermometer before I give it back and so . . . I mean . . ." Doctor: "What has the reading been?" Patient: "Well, they still take it rectally and it's almost 101° this morning." Doctor: "Is there some way, then, in which they are not telling the truth?" Patient: "Well, they seem to be telling the truth, I guess."

From the above and similar conversations with the patient it appeared that, although she had all the facts in a given situation, nevertheless she was unable to relate them to each other in a meaningful way.

Following the operation the patient's pain was improved and she noted, "The actual nature of the pain has changed, but the pain is still here. It's in the same area, except it isn't as strong" On returning home she found that she was markedly slowed down so far as her ability to perform household tasks was concerned. An example of this was the fact that she noted it would take her three hours or more just to clean the stove, or that it would take her all day to clean her room. This was due to the fact that it was necessary for her to think of each step separately or, if she did not and permitted her mind to wander, she would find that she had dusted the same spot for five minutes In addition to this she noted that she found it very, very difficult to remain in the house, that she had a constant desire to go out and just walk in the streets, not going anywhere in particular At times she would find herself in various places, not knowing how she got there and not having recognized any particular scenery along the way. She further noted some impairment in memory in the sense that she found it impossible to remember what the houses on her street looked like, although she saw them every day and had for many years. The patient continued to take large doses of medication, although at first she admitted that her pain was better. The operation seemed to have had no effect so far as her addiction was concerned.

There was gradual improvement in each of the above-described difficulties and after three to four months her inability to express her feelings in words, her inability to put thoughts in writing, her intermittent loss of the symbolic meaning of words, and her inability to synthesize thoughts into meaningful wholes had completely disappeared. A slight flattening of the affect had persisted up to her last visit. In addition the patient noted that she was still restless and that it might require twice as long to do things as prior to the leucotomy.

Six months after the leucotomy she complained that her left-sided neuralgia had again returned to its original intensity. A second spinothalamic tractotomy was therefore carried out at C2 on the right, and has resulted in lasting alleviation of her previous neuralgia (see pp. 219, 270, 423).

4. Speech Analysis Before and After Unilateral Leucotomy

Decrease in spontaneous speech was studied by means of recorded interviews of seven patients before and after unilateral leucotomy. Analysis of the larger parts of the interviews—a) the patients' speaking time, b) the doctor's speaking time, c) the patients' waiting time before responding to the intervention or prodding of the doctor, and d) the doctor's waiting time before intervening—reveals, as seen in Figure 90, a drop of 18 per cent in the patients' speaking time following operation and an increase in waiting time (the interval between the doctor's intervention or prodding and the patients' speaking).

The percentage of the doctor's speaking time showed no appreciable change (Fig. 90), but Figure 91 indicates that there was a significant increase in the number of interventions (significant at the 2 per cent level). This seems to indicate that the patients' lowered responsiveness made the doctor increase the number of interventions in order to "draw the patient out."

Figure 92 gives the rate of speech in terms of mean words per minute for each patient before and after unilateral leucotomy. In every case, except that of Patient G. F., there is a decrease in the rate of speech flow after operation. The group mean preoperatively was 143.8 words per minute, and postoperatively it fell to 118.2. This was found to be significant at the 5 per cent level.

In summary, 16 pre- and 19 postleucotomy (unilateral) recorded interviews on seven patients were analyzed. It was found that the patients have a tendency to speak less during interviews after operation, the rate of speech in words per minute is reduced, and they take longer to respond to the doctor's interventions. Recovery to normal occurred in about six months.

5. Theoretical Discussion

In important studies of the psychological effects of frontal lobotomy performed for the alleviation of pain Watts and Freeman (1948) and Koskoff, Dennis, Lazovik, and Wheeler (1948) make the convenient distinction between *suffering* and *pain*. They emphasize that frontal lobotomy is surgery for the relief of *suffering* rather than for the relief of *pain*. In order to understand suffering one must have a comprehensive knowledge of the patient. In treating suffering a complex entity, the personality, is

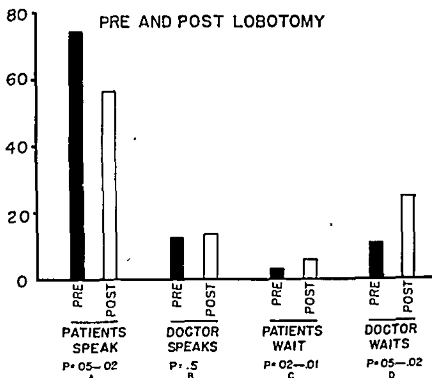


Fig. 90. Speech analysis before and after unilateral leucotomy: Graph of the larger parts of interview time in per cent.

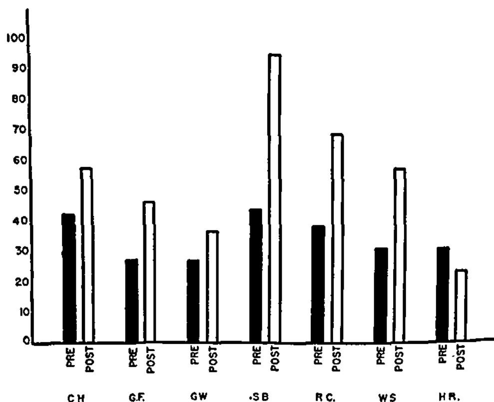


Fig 91. Speech analysis before and after unilateral leucotomy. Graph of mean number of interventions.

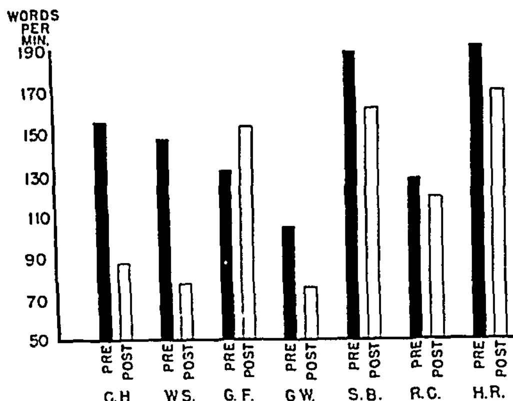


Fig. 92 Speech analysis before and after unilateral leucotomy. Graph of rate of speech in words per minute.

being attacked therapeutically. In the paper by Koskoff *et al.* on the concept of suffering, the question whether the pain is described as a sensation, a perception, or an emotion, becomes academic. They conclude that:* "The relief of suffering may be achieved as a result of the interruption of association pathways forming part of a vicious circle. Organic irritants activating long-circuiting afferent impulses allow for the bombardment of internuncial pools at frontothalamic levels. Psychic irritants with eventual somatic effects may bombard the same areas. Frontal lobotomy surgically interrupts the association pathways in this circle."

Here is a neurological explanation of the effects of leucotomy. It brings in the concepts of association paths, long-circuiting, and vicious circles. For an hypothesis to explain the relief of suffering by frontal gyrectomy or leucotomy, the concept of long-circuiting seems to be basic It was implicit in Sherrington's work on the integration of the nervous system and, as far as we know, was first mentioned in print by Fulton in 1926. One of us took it up and applied it to the idea of human intelligence in 1936 and later to

*Koskoff, Y.D., Dennis, W , Lazovik, D , and Wheeler, E T The psychological effects of frontal lobotomy performed for the alleviation of pain *Res Publ Asso. Nerv. & Ment. Dis*, 27·723-753, 1948.

explain the effects of leucotomy (Cobb, 1943). Freeman and Watts (1950) consider it a useful explanation for the effects of "psychosurgery." The concept may be summarized in a simplified mechanistic explanation as follows:

A sensory stimulus is received in the thalamus and relayed to the appropriate cortical sensory area. It then spreads over many associative fibres to other neighbouring areas, awaking old associations and arousing responses conditioned by past experience. Eventually these spreading stimuli are gathered in from their long-circuiting and projected onto the motor areas, to be transformed into motor acts. In short, the crude sensory stimulus arrives in the subthalamus and thalamus and is relayed to the cortex. Here it is widely spread so that former conditionings are aroused, and finally the stimuli converge on the motor cortex and are expressed in motor behaviour. The greater the long-circuiting through association areas the greater is the conditioning of the response. Reactions are delayed and modified by past experience. The more one acts in the light of experience, the more intellectual is the response. The ability to "look ahead" and act "intelligently" is the great asset of man. No other animal can do this to any important extent.

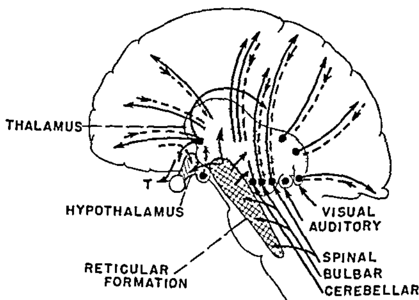


Fig 93. Diagrammatic representation of the mechanism that activates the forebrain.

This was suggested by recent experimental work. Afferent impulses from various sensory end-organs reach the thalamus and are relayed to the cerebral cortex, where returning neurones form thalamocortical circuits. Before reaching the thalamus the spinal, bulbar, and cerebellar tracts give off collateral branches to the reticular formation of the brain stem, which then acts as an activating mechanism for both thalamus and hypothalamus. Leucotomy and gyrectomy may interrupt the frontal thalamocortical circuits and the paths from the frontal areas to temporal cortex (T) and to the hypothalamus.

The size of the overlying cerebrum is purposely reduced in this diagram in order to conserve space.

Since Koskoff *et al.* (1948) wrote their paper in 1947 some important theories have been promulgated that enhance the importance of these neuronal circuits, benign and vicious. Wiener's *Cybernetics* published in 1948 put together facts taken from the field of communication engineering concerning the switching devices, electronic circuits, and feed-back of the modern calculating machines. These may well make a mechanical model that has important analogies with the mechanisms of the human cerebrum (von Foerster, 1951). Much is known now about the neuronal circuits between thalamus and cortex (Brazier, 1951). The essential mechanism from the physiological point of view is an arrangement of neurones that can keep up a sustained state of activity following a few intermittent stimuli. For this the mechanism sketched in Figure 93 is admirably suited. The tract from hypothalamus to thalamus tends to keep the latter awake and ready to

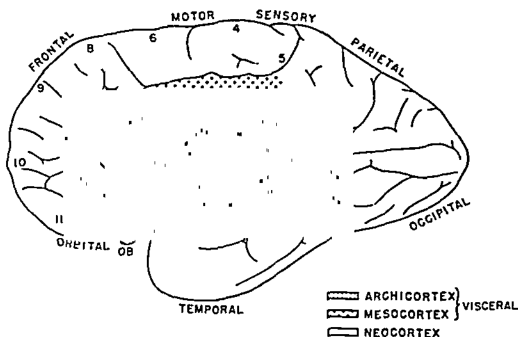


Fig. 94 Position of areas representing the archicortex and mesocortex, often alluded to as the "visceral brain."

receive impulses from cord and brain stem. The neuronal circuits from thalamus to cortex and back supply the mechanism for sustaining a stimulus by reverberation, once the thalamus has been stimulated. The ascending reticular activating system, described by Magoun (1952) in the brain stem, could set these thalamocortical circuits going. Magoun shows that single shocks to the sciatic or splanchnic nerves can set up prolonged reactions in this reticular alerting mechanism.

Of great interest also is the neurological mechanism of emotional reaction proposed by Papez in 1937 but only recently taken up and elaborated

explain the effects of leucotomy (Cobb, 1943). Freeman and Watts (1950) consider it a useful explanation for the effects of "psychosurgery." The concept may be summarized in a simplified mechanistic explanation as follows:

A sensory stimulus is received in the thalamus and relayed to the appropriate cortical sensory area. It then spreads over many associative fibres to other neighbouring areas, awaking old associations and arousing responses conditioned by past experience. Eventually these spreading stimuli are gathered in from their long-circuiting and projected onto the motor areas, to be transformed into motor acts. In short, the crude sensory stimulus arrives in the subthalamus and thalamus and is relayed to the cortex. Here it is widely spread so that former conditionings are aroused, and finally the stimuli converge on the motor cortex and are expressed in motor behaviour. The greater the long-circuiting through association areas the greater is the conditioning of the response. Reactions are delayed and modified by past experience. The more one acts in the light of experience, the more intellectual is the response. The ability to "look ahead" and act "intelligently" is the great asset of man. No other animal can do this to any important extent.

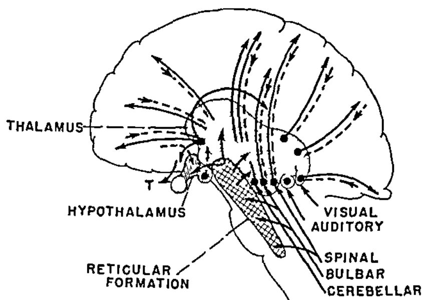


Fig 93 Diagrammatic representation of the mechanism that activates the forebrain

This was suggested by recent experimental work. Afferent impulses from various sensory end-organs reach the thalamus and are relayed to the cerebral cortex, where returning neurones form thalamocortical circuits. Before reaching the thalamus the spinal, bulbar, and cerebellar tracts give off collateral branches to the reticular formation of the brain stem, which then acts as an activating mechanism for both thalamus and hypothalamus Leucotomy and gyrectomy may interrupt the frontal thalamocortical circuits and the paths from the frontal areas to temporal cortex (T) and to the hypothalamus.

The size of the overlying cerebrum is purposely reduced in this diagram in order to conserve space.

brain. A moderate pain might cause and perpetuate much suffering because of widespread activation of the cortex.

The theory justifying leucotomy is simply that a reduction in the number of activated circuits may reduce the abnormal activity enough to give relief. This is the quantitative aspect. Also there is the probability that after a cerebral wound reintegration must take place. The whole cerebral mechanism organizes itself to go on functioning in a new *Gestalt* and at a somewhat less complex level. During this period of reintegration it may be that some functions are lost for a period, a possible explanation of the temporary dysfunction seen after unilateral leucotomies for five or six months. Finally, it is possible that cutting specific tracts is important. For instance, if the connections between neocortex and archicortex were severed one might speculate that there would be less activation of the archicortical circuits, which probably subserve emotional reactions and thus perpetuate suffering. This gives a rationale for the orbital gyrectomies and lower quadrant leucotomies.

There is no good explanation for the observation that patients leucotomized for pain seem to suffer much more mental deficit than those leucotomized for psychosis. One might speculate with Wiener (1948) that it is because the psychotic patients are usually agitated or obsessive and their relief comes from the reduction of activity by cutting out already overloaded circuits. Thus the psychotic patient is reduced from hyperactivity to a normal level, wheras the patient with pain has his cerebral circuits reduced from a normal to a subnormal status.

C. POSTCENTRAL GYRECTOMY

The postcentral gyrus, which includes areas 1 to 3 of Brodmann throughout its length and in its superior portion a part of area 5 as well, is the principal cortical station for sensory integration. As has been pointed out in Chapters II and III, the thalamic sensory projections are distributed to other areas in the parietal cortex and also to a certain extent to the frontal lobe.

Head and Holmes (1911) described a patient in whom a cerebral vascular lesion eliminated all recognition of posture in a phantom limb. But not until 33 years later did de Gutiérrez-Mahoney (1944) map out and resect the appropriate portion of the postcentral gyrus with a view to eliminating pain in a phantom limb. At first this procedure appeared to be a practical solution to the problem of phantom pain, but prolonged follow-up of the cases reported in Chapter XII has shown that there has been a gradual recurrence, if not early failure, in many of them. This is undoubtedly due to the impossibility of resecting the entire sensory representation of the affected limb. Postoperative seizures are a complicating factor. The opera-

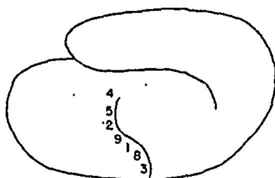
by others (MacLean, 1949; Cobb, 1950). In this concept of the neurology of emotional phenomena the archicortex and mesocortex (see Fig. 94) are taken together and described as the old "visceral brain" in contradistinction to the neocortex. This visceral brain is largely the cerebral area that used to be called rhinencephalon and comprises hippocampus, amygdala, uncinate gyrus, cingulum, and the posterior parts of the orbital gyri of the frontal lobe. The olfactory organs are, of course, included and form an important element. Every sentient human being has experienced the close relationship of smell to emotion. The neocortex is largely integrated with the thalamus by the thalamocortical circuits (Fig. 93). The visceral brain receives impulses not only from the olfactory bulb but from the other sensory tracts as well (Brodal, 1947B). These are integrated in the hippocampus. The visceral brain is thus activated and adds its background of emotional feeling to the total reaction. It discharges largely into the *hypothalamus*, thus setting up autonomic reactions in the vessels and viscera. A tract from areas 12 and 13 in the orbital part of the frontal cortex may be a link between the neocortex and the visceral brain (Ward and McCulloch, 1947).

One can conceive of a great many neuronal circuits in these combined mechanisms. In both old and new parts of the cerebrum the circuits are activated by sensory impulses of many kinds, their activity continuing long after the activating stimuli have ceased. That sensory stimuli do spread to many areas by associative pathways is well known. That sensory stimuli are stored as memories is also common knowledge. The phenomenon of the phantom limb is probably a complex sensory memory stored in the central nervous system where there is considerable integration of neurones.

Support to the theory of long-circuiting is given by French, von Amerongen, and Magoun (1952) and by Starzl and Whitlock (1952) from experiments on monkeys. The experimental evidence for this, published by the investigators working in Magoun's laboratory, is summarized in Chapter II. These in turn activate widespread potentials in the cortex, especially in the sponses in the reticular formation in the brain stem by way of collaterals. These in turn activate widespread potentials in the cortex, especially in the frontal and anterior parietal regions. They even raise the question as to whether the laconic postlobotomy state in man may be the result of isolation of a large area of cortex from the activation system.

To apply all this to painful stimulation one has merely to think of the stimulus as greatly increased. The levels of receptor end-organ, sensation, perception, and emotion may be thought of as levels of increasing complexity of the central nervous system to which the stimulus ascends, with more and more associations aroused and different neuronal circuits activated. The total effect on any one brain of a strong sensory stimulus may be small or great, important or insignificant, according to the life history of that especial

Helen C., 56 Thalamic Pain



4 - Closed Mouth
5 - Compressed Lips
2 - Movement of Eyelids
9 - Neck Muscles Tightened
1 - Movement Thumb and Index Finger
8 - Movement of Hand
3 - Movement of Shoulder

No Subjective Sensation on Stimulation

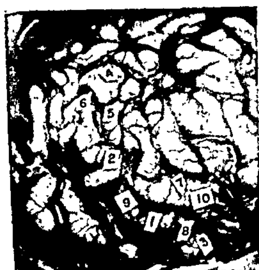




Fig. 95. Postcentral gyrectomy: Electrical mapping of central sulcus and extent of removal. This patient with thalamic pain had satisfactory relief for 18 months, but then had ultimate return of left-sided dysaesthesia to its former intensity (see page 530).

can be removed from the pial curtains dipping into the sulci without starting haemorrhage which requires electrocautery for control. Application of gelatin foam soaked in thrombin should arrest any oozing which does not stop spontaneously. Maximal preservation of the overlying pia reduces the degree of meningocerebral cicatrix and is the best protection against ischaemia of the remaining cortex or development of postoperative epilepsy. Prophylactic doses of Dilantin should be given during convalescence and gradually withdrawn under electroencephalographic control.

The patient in whom we have carried out the most thorough stimulation and the most extensive, but fruitless, removal is described below:

Adeline R., Memorial Hospital, Pawtucket:—This 60-year-old woman had had for 10 years pain in the left costovertebral angle, lower chest, upper flank, and hypochondrium. Numerous studies, including one upper abdominal exploration with splenectomy, had been to no avail. In March, 1947, Dr. Hannibal Hamlin had carried out a left posterior rhizotomy from T3

tion has ultimately failed in such a high proportion of cases that recent enthusiasm for it appears to be on the wane. A thorough follow-up of over 30 cases done by many surgeons all over the world is now being made by de Gutiérrez-Mahoney. Since it is still a procedure in current use, a brief description of the technical steps is given herewith:

Postcentral gyrectomy should be carried out under local anaesthesia, as cortical irritability must be preserved to permit detailed mapping of the motor-sensory representation by electrical stimulation. Moderate sedation, however, can be obtained by repeated increments of Pentothal or Demerol intravenously. A small bone flap is cut down, centred above the ear, and carried well up towards the midline to expose the Rolandic fissure with its pre- and postcentral gyri. When the sensory area for the leg is to be resected the exposure must extend to the longitudinal sinus, since in some instances the representation of the lower limb lies wholly on the medial surface of the hemisphere. The first step is to map out the motor area of the arm or leg or, in the case of thalamic pain, of the entire opposite side. This we accomplish by use of the Grass stimulator producing square waves, with a setting of 1-2 milliseconds duration, a frequency of 30-60 per second, and a potential from 3 to 7 volts. The lowest strength of current capable of producing a clearly defined movement or sensation should be used. After each response we place a numbered paper ticket on the cortex to mark the point from which it was evoked. When the desired area has been mapped it is then photographed for a permanent record (Figs. 95 and 96). We have sought especially to reproduce or intensify the patient's clinical pain by properly placed stimulation at appropriate parameters. In Adeline R. (Fig. 96), even though we increased the patient's pain by stimulus to the suspected part of the postcentral zone, we did not stop the pain by removal of this area. In Robert S. (p. 413) Dr. J. T. B. Carmody tried the additional procedure of injecting procaine subpially in those portions of the postcentral gyrus concerned with the painful areas. This tactic stopped the pain in dramatic fashion in each phantom finger as the appropriate area of cortex was procainized. After postcentral gyrectomy the pain remained absent for several months, only to recur. Adeline R.'s pain was not stopped by subpial procaine in the postcentral gyrus.

After the motor and sensory areas have been delineated, one removes the appropriate portion of the postcentral gyrus subpially by suction, extending the resection from the postcentral sulcus forward and deeply to include the posterior bank of the central sulcus. Care should be taken to leave its pia and the Rolandic vessels intact. Suction removal must be carried down to the extreme depth of cortical grey matter along the anterior and posterior banks of the postcentral convolution, so that only the underlying white matter remains at its base. By gentle suction the entire gyrus

through the upper rootlets of T7. This produced anaesthesia from the third rib nearly to the umbilicus but did not stop the pain. In November, 1947, he carried out a right cervical cordotomy at the upper border of the C2 segment. This yielded thermanaesthesia and analgesia from the C4 segment on down and relieved all pain in the left torso. Unfortunately it was followed by burning pains in the left foot and leg and in the whole left upper limb, pains of which there had been no inkling prior to cordotomy. Sensory examination in April, 1948, showed analgesia both to single pinprick and deep continuous pin scratch from C4 down, except that the latter vigorous stimulus caused slight discomfort over the plantar surface of the left foot and toes, and in scattered areas along the medial and lateral borders of the foot.

In view of the presumed locus of the irritant lesion in the uppermost cervical cord right postcentral gyrectomy was performed on April 16, 1948. Figure 96 shows the areas whose stimulation yielded motor and/or sensory responses. At numbers 22, 23, 24, and 26, all in the postcentral gyrus, a burning sensation was evoked at one or more areas below the left knee. This was described as a worsening of the similar sensation already present. At number 20 she felt "needles all through the left hand." Discomfort was elicited from no other stimulus, but resection included the whole postcentral gyrus for the limbs and torso and extended on the medial surface of the hemisphere down to the sulcus cinguli. Burning in the left heel continued while the patient was still in the operating room and the operation gave her no relief from the pain in either the left arm or leg.

A secondary right upper thoracic cordotomy in December, 1948, was of no avail, but left frontal leucotomy done later that month gave partial relief, which persisted in July, 1952, so that the patient was then no longer taking analgesic drugs.

After complete or partial resection of the postcentral gyrus the following neurological changes have been observed by various surgeons. There has been transitory hemiplegia and/or aphasia from oedema spreading forward

←

Fig. 96. Postcentral gyrectomy for pain brought on by cervical cordotomy (Adeline R.). Complete failure to obtain relief. Responses indicate that central sulcus lies just behind numbers 10, 1, 11, 17, 9, 19 All responses confined to limbs or torso except that at 5 sensation of motion left side of mouth. Sensory responses at 1, 11, and 19 in precentral gyrus, motor responses at 13, 15, and 23 in postcentral gyrus; otherwise responses motor from precentral, sensory from postcentral gyrus. At 1, sensation of "stiffness" in left hand At 11, felt as though left knee moved. At 19, felt as though left inguinal region moved—i e., no pain evoked from precentral gyrus At 10, 17, 9, 21, 14 various motions left forearm, hand, or fingers. At 16, motion left lower limb. At 18, motion both left limbs. At 2, 6, 8, 4, sensations left hand or fingers. At 3, felt as though left shoulder moved. At 7, felt as though left lumbar region moved. At 22, 23, 24, 26, burning at various areas below left knee.

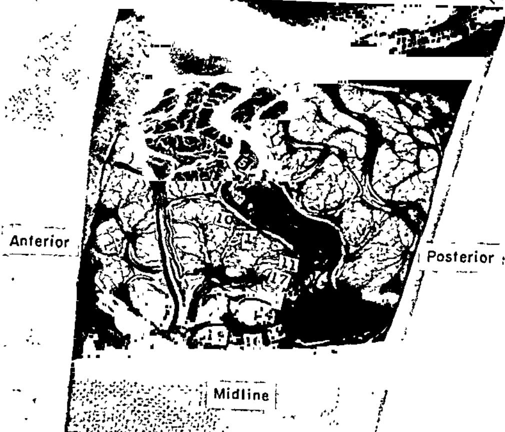
This operation was performed by Dr. Hannibal Hamlin and one of us We are indebted to Dr Hamlin for permission to publish these photographs and other details of the case.

5

2

Posterior

Midline



See legend on opposite page. 

cheek had relief for only five days from a right postcentral cortical removal of the face area as delimited by sensory responses to stimulation. No relief followed further removal five months later of an area from the left (ipsilateral) cortex. This gave no responses of movement or sensation upon stimulation, but was selected for extirpation because the responses from the gyrus just anterior were exclusively motor, and those from the next rostral gyrus were turning of the head to left and tremor of forearm. Nevertheless at postmortem 27 months later the postcentral gyrus on this left side was found to be immediately anterior to the gyrus actually removed. The experience emphasizes the value of obtaining a number of sensory responses for proper identification of sensory koniocortex in vivo.

Postoperative seizures are likely to develop and were a complicating factor in two of our three cases. Fortunately the spells have not been severe and have responded well to Dilantin. However, the patient of David, Talairach, and Hécaen (1947) died in convulsive seizures on his fourth postoperative day, illustrating the importance of prophylactic anticonvulsant medication as a routine postoperative measure. Browder (1950) mentions a further patient with only temporary relief and in whom the situation became "infinitely worse, as a result of recurring convulsive seizures."

For the results of postcentral gyrectomy in the treatment of painful phantoms see pp. 410–415. Unless the high percentage of failures of postcentral gyrectomy can be reduced, it should be given up. Possibly more extensive resection of brain in the cortex described as sensory by Bailey *et al.* (1940) may prove effective (see Fig. 18). As a means both of reducing the tendency to seizures and of resecting a wider area of sensory cortex when the lesion is on the nondominant side, Pool's suggestion (personal communication) of undercutting areas 1, 2, 3, 5a, and 7a (as delineated in Fig. 15) may prove a valuable method. In the case he has reported to us he first placed a row of needles in the Rolandic fissure and then undercut the cortex up to this point by a leucotome inserted far back in the parietal lobe. His single case (mentioned on p. 110) has been relieved of a painful phantom arm for over a year. This method deserves careful exploration in suitable cases.

over the precentral gyrus. This soon clears, as is the case after other operations in close proximity to area 4 when there has been no direct injury to the motor cells or their blood supply. Sensory loss does not include full-fledged analgesia; its exact character and extent could not be determined, as we have always done these operations when the extremity has been amputated or suffered previous damage to the cerebral or spinal neurones that conduct pain.

The ultimate results of postcentral gyrectomy in the treatment of "central" pain have been variable. One of our patients (Helen C., MGH U-632940), operated upon for thalamic pain, was at first considerably improved, only to have the pain return at the end of 18 months. It is also of interest to note that this patient had obtained no relief of her burning hemidysaesthesia after a spinothalamic tractotomy in the upper cervical region, which produced complete analgesia to her chin. Penfield and Welch (1951) have reported a similar failure after postcentral gyrectomy, in which the early relief of thalamic pain was followed by a gradual return of the former discomfort. Dimitri and Balado (cited by David, Talairach, and Hécaen, 1947) also failed to secure relief of thalamic pain by this operation. In contrast to these late failures Erickson, Bleckwenn, and Woolsey (1952) have recorded two long-term striking successes with the procedure in instances of pain of central origin. The first patient had the typical full-blown thalamic syndrome of Déjerine-Roussy after a "stroke," with burning pain referred to the entire left face, torso, and limbs. Following removal of the whole postcentral gyrus this patient had no more left-sided pain for the remaining two years of her life. The second patient had severe pain in the left arm along with many other evidences of syphilitic disease of the brain. Intensive antiluetic therapy failed to stop the pain, but postcentral gyrectomy of the arm and extending on into the hip area has given the patient nearly complete relief for the ensuing four years. Horrax (1946) has reported after this operation the disappearance of central pain caused by a deep temporal cerebral lesion; relief lasted for only five months in the upper limb, but was maintained for over 14 months in the lower. In a second man, whose pain in the right arm followed removal of a left frontal astrocytoma, relief of pain was complete for the remaining 10 months of his life. In a third, pain in an upper limb was related to bone in the spinal canal ventral to the cord "at C6 level"; postcentral gyrectomy gave inadequate relief.

In two reported patients the procedure has failed to relieve facial pains. Odom and Lyman's (1946) case of atypical facial neuralgia not only continued with pain but had a persistent "ataxic dysarthria" of speech after postcentral gyrectomy of the face area in the dominant hemisphere. Sugar and Bucy's (1951) patient with postherpetic neuralgia in the left eye and

lumbosacral plexuses with radiation to the back and legs, sympathetic denervation is useless. The surgeon must then shift his attack to the anterolateral quadrants of the cord.

A. THORACIC SYMPATHETIC GANGLIONECTOMY

For relieving pain of visceral origin actual resection of the ganglia is preferable to ramisectomy or other modifications that have been proposed, because it is the simplest procedure to carry out and the least liable to be followed by fibre regeneration. It is advisable to use endotracheal ether anaesthesia, as the pleura is occasionally torn, and to avoid operation in the prone position on all but young and vigorous individuals. The experienced surgeon will find that exposure in the semilateral position (Fig. 97 insert) is just as easy for himself and far safer for his patient, who is spared the handicap of limited thoracic and abdominal expansion with reduction in negative intrathoracic pressure and consequent poor venous filling of the heart. Excessive drops in blood pressure are all too common in the prone position, but rare if the patient, even an elderly, obese individual, is placed on his side.

Whenever the pleura is opened the two great problems of oxygen supply and carbon dioxide removal increase in complexity. With the ordinary types of anaesthetic apparatus which provide for carbon dioxide absorption and rebreathing of the gases in a closed system, oxygen supply is no problem in the usual case. Beecher (1950) and Gibbon *et al.* (1950) have shown that the other half of the problem, carbon dioxide removal, will usually not be adequate with the patient in the lateral position, unless the anaesthetist increases the patient's spontaneous ventilation by gently compressing the breathing bag each time the patient begins to inspire. The rise in carbon dioxide tension begins as soon as the patient is placed in the lateral position, even before the pleura is opened, and rises to dangerous levels in some cases when the pleura is open.

The general technique of thoracic sympathectomy is the same, regardless of whether the upper thoracic ganglia are to be removed for cardiac pain or the ganglia above the diaphragm together with the splanchnic trunks for biliary tract or pancreatic pain. For cardiac denervation the paravertebral incision is centered over the second rib, 5 cm. lateral and parallel to the uppermost prominent spinous processes, as originally described by Adson (1931). The trapezius, rhomboids, and serratus posticus superior muscles are transected, and the second rib is identified by ascertaining that there is only a single one above. Its central 4 cm. segment is stripped of periosteum and resected, together with the protruding transverse process (Fig. 98).

Exposure of the lateral aspect of the vertebra, where the sympathetic

CHAPTER XI

SYMPATHECTOMY FOR VISCERAL AND CAUSALGIC PAIN

As long as pain of visceral disease remains purely local in origin it can best be relieved by resection of the regional sympathetic nerves.* Only when malignant growths spread to infiltrate adjacent tissues and thereby involve the cervical, thoracic, and lumbosacral plexuses or periosteum, is cordotomy necessary. We are well aware that certain reports have claimed that pain in malignant disease originating in the viscera can be relieved by sympathectomy. It is our opinion, however, that the authors have made unjust claims for the efficacy of sensory denervation limited to an organ such as the pancreas or uterus, as the postoperative follow-up has invariably been too short. Early results only, based on the patient's condition at discharge or a few weeks later, as in the recent paper of Trimble and Morrison (1952), should never be published. In several of our cases of carcinoma of the pancreas the patients were relieved of pain for the first few weeks after splanchnicectomy, but pain soon recurred. On the other hand, pain of angina pectoris, of disease leading to distension of the biliary and pancreatic ducts, or the renal pelvis and ureter, as well as idiopathic dysmenorrhoea, can be relieved most effectively by denervation limited to the visceral nerves. Such operations carry practically no danger in the ordinary fair-risk patient and lead to no lasting disturbance greater than a Horner's sign, or a dry and warmer extremity.

Sensory fibres reach the viscera via the sympathetic rami communicantes, paravertebral ganglia, and splanchnic plexuses. The vagi below their tracheal rami contain no pain-conducting fibres. This is true of the craniosacral autonomic outflow in general, with the unfortunate exception of the sacral rami. Vesical pain is transmitted almost entirely by the inferior hypogastric plexus and rami from the second, third, and fourth sacral nerves. These cannot be cut without causing paralysis of micturition and loss of tone in the sphincter ani. Sensation from the prostate and uterine cervix follows a similar route. In these conditions, or when cancer of the uterus and abdominal organs has spread via the paravertebral lymphatics to compress the

*It must be re-emphasized here, as explained in Chapter III, that visceral trunks are mixed nerves. The true sympathetic fibres are purely motor, while the afferent fibres that conduct pain differ in no wise from somatic axones that carry disagreeable sensation from other deep structures and the surface of the body.

chain lies, is greatly facilitated if the surgeon rongeurs away the transverse process with the head of the rib. In good risk patients with long life-expectancy it is advisable to remove a similar section of the third rib as well, so that a greater length of ganglionated chain can be removed and the chance of nerve regeneration thereby reduced. Because of possible weakening of the spinal column, we are somewhat reluctant to advise routine

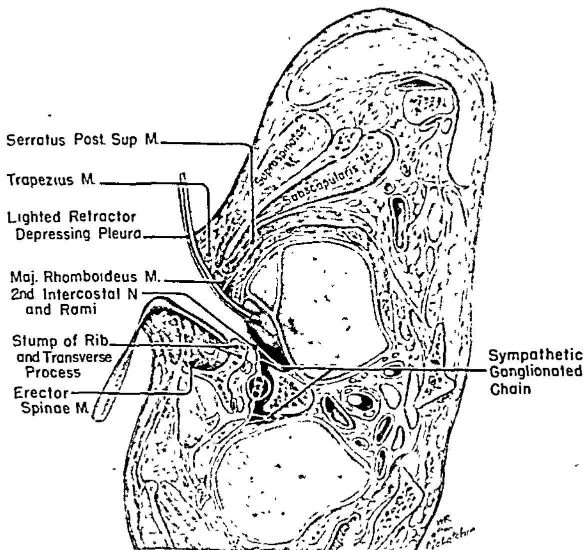


Fig. 98. Upper thoracic sympathetic ganglionectomy: Cross section anatomical diagram to illustrate the posterior paravertebral exposure and position of the upper thoracic sympathetic ganglia.

removal of sections of two adjacent ribs on both sides. In the event of a bilateral two-stage procedure it is perhaps better to do the double rib resection on only the side of the worse pain, or to stagger the resections, removing the central ends of ribs 2 and 4 on one side, 1 and 3 on the other. In some of the patients in whom ribs 11 and 12 have been removed bilat-

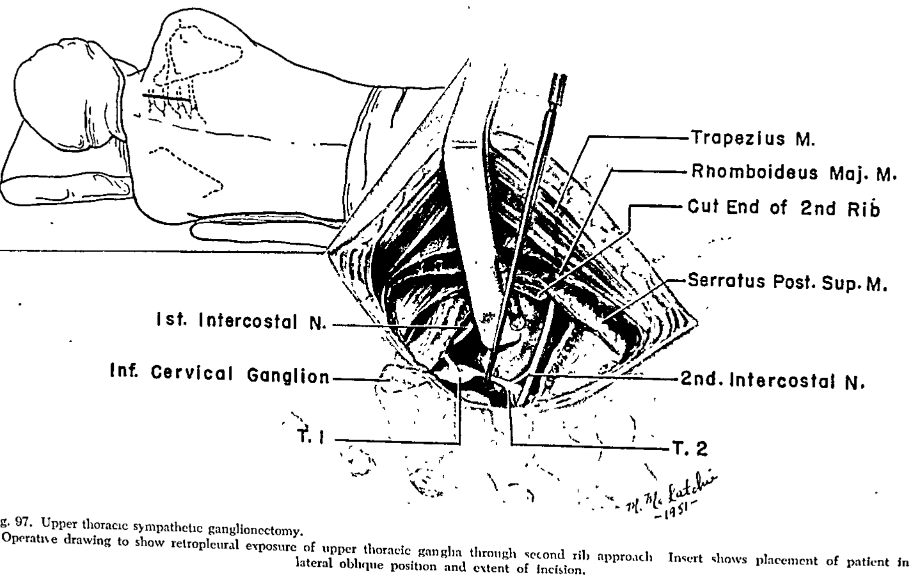


Fig. 97. Upper thoracic sympathetic ganglionectomy.
Operative drawing to show retropleural exposure of upper thoracic ganglia through second rib approach. Insert shows placement of patient in lateral oblique position and extent of incision.

Preganglionic denervation of the upper extremity, as distinguished from upper thoracic ganglionectomy, is recommended only for cases of post-traumatic neuralgia of the upper extremity. This operation avoids the minor disfigurement of a Horner's sign and has given good results in cases of causalgia, Sudeck's post-traumatic dystrophy, and certain peripheral amputations where pain is associated with cold, cyanotic, and sweaty skin.

Because it is our belief that pain in these conditions will rarely if ever recur, even in the event of late regeneration of sympathetic fibres, we are now advocating a simplified form of preganglionic sympathectomy which was first used by White in 1935 (unpublished data). This consists of removal of the second, third, and fourth thoracic ganglia. Practically all preganglionic fibres to the arm are interrupted thereby, as these arise from the second to eighth or ninth thoracic segments and run upwards through this portion of the chain before establishing synaptic connections with the postganglionic neurone cells in the lower cervical and first thoracic ganglia, which in turn supply the grey rami to the brachial plexus.

This modification of sympathetic denervation of the upper extremity spares the ocular fibres in the eighth cervical and first thoracic white rami, and thereby avoids the syndrome of Claude Bernard-Horner, which is somewhat disfiguring after a unilateral procedure. It is far simpler and more rapidly performed than Smithwick's modification (1940), although not effective in the treatment of Raynaud's disease because more definite regeneration may take place after nine to 12 months. In case the patient desires permanent relief from troublesome vasospasm as well as pain it is advisable to fall back on one of the more extensive forms of sympathectomy described in White's book with Smithwick and Simeone (1952). Permanent interruption of vasomotor tone does not appear to be necessary in the post-traumatic dystrophies, since once full use of the hand is regained there is little tendency to recurrence.

Removal of the lower thoracic ganglia without including the splanchnic nerves is rarely if ever indicated. The combined resection of these structures is discussed below.

B. LUMBAR SYMPATHECTOMY

Removal of the lumbar sympathetic ganglia is an effective method of relieving causalgia in the lower extremity and such conditions as Sudeck's atrophy and other varieties of pain associated with trauma and excessive vasospasm. As there is no danger of opening the pleura, this operation can be performed under spinal as well as under ordinary ether anaesthesia.

The position of the patient is a matter of considerable importance in the ease with which the anterolateral surface of the lumbar vertebrae can be

erally in operations for hypertension, we have observed backache lasting for months and even years.

After the opening has been made in the thoracic cage, the surgeon should free the parietal pleura widely from the central ends of the upper four ribs and sides of the corresponding vertebrae. When this has been carried out, insert a lighted retractor and search for the thoracic chain by inspection and blunt dissection of the lateral aspect of the exposed vertebral bodies (Fig. 98). The chain always remains attached to their sides where it loops over the central ends of the ribs, and its ganglia are connected by rami a few millimeters in length to the corresponding intercostal nerves.

With exposure gained by removal of the second rib the chain can be divided below its third or fourth ganglion and then, by downward traction and division of connecting rami by which it is anchored, the much larger first ganglion, and usually the inferior cervical as well, can be drawn down into view from beneath the first rib (Fig. 97). Removal of this section of the trunk is sufficient to stop ipsilateral precordial and arm pain in angina pectoris. It cannot be counted on to stop radiation of coronary pain to the neck and jaw (see page 617). If sections of two ribs are removed, the ganglia can be resected from the inferior cervical above to the fourth or fifth thoracic below, an extent which ensures even greater certainty of relief in case of anatomical variation and is far more certain to prevent regeneration, which has resulted in recurrent anginal pain in a few cases (see Pt. 6B, p. 636) after respites of a year or more.

We prefer to apply a dural clip to each ramus before it is cut, not only because small branches of the neighbouring intercostal vessels may be severed and give rise to troublesome bleeding, but also for subsequent x-ray demonstration of the exact extent of chain removed. If a small opening is made in the pleura, it is usually advisable to enlarge it so that the extent of lung expansion can be observed and to permit insertion of a catheter at the time of closure for removal of residual air. Closure is effected by suturing the divided muscles, fascia, and skin with fine interrupted cotton or silk sutures.

Some surgeons prefer to employ Gask's (1933) anterior supraclavicular approach for removal of the upper thoracic ganglia. (For a description of this operation see White's Chapter 19 in Bancroft and Pilcher's *Surgical Treatment of the Nervous System*, 1946, or Chapter XVI in the monograph on *The Autonomic Nervous System* by White, Smithwick, and Simeone, 1952.) We have used it on a number of occasions, but it does not give as adequate an exposure for an extensive removal of the chain and, with the adoption of the lateral position of the patient on the operating table, it is no longer necessary for the maintenance of good respiratory exchange or prevention of excessive falls in blood pressure.

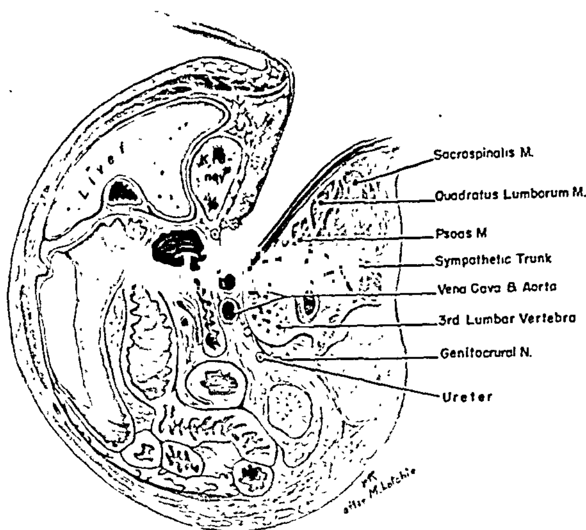


Fig. 100. Lumbar sympathetic ganglionectomy.
Cross section anatomical diagram to illustrate the posterior paravertebral exposure of the lumbar ganglia.

at this point and can easily be identified by palpation, as it feels just like the vas deferens in the spermatic cord. Care must be taken not to mistake the genitofemoral nerve for the chain, as it runs down the anterior surface of the psoas a centimeter or two lateral to the chain. Lymphatic trunks and even the ureter have been resected by mistake. With care to identify the ganglia and their emerging rami communicantes no such error is possible.

To obtain a good exposure in this deep angle, place a roll of handkerchief gauze beneath a broad abdominal retractor and have an assistant on the opposite side of the table retract the kidney, ureter, and peritoneal contents toward the midline. A lighted Deaver retractor held by a second assistant standing beside the operator is of value for depressing the medial attachment of the psoas muscle and illuminating the field. It is also helpful at this stage

exposed. For the paravertebral approach through the lumbar fascia, which involves the minimum of damage to muscle and nerves in the abdominal wall, it is best to have the patient in the lateral position with the lower leg extended and the upper flexed at the hip and knee and supported on a pillow (Fig. 99). This relaxes the psoas muscle, which in a muscular individual may otherwise bulge and obscure the view of the paravertebral gutter. The table must also be broken in the lumbar region to widen the distance between the lowest rib and the iliac crest. *The incision is made* over the line of attachment of the abdominal muscles to the longitudinal sacrospinalis group. It should start just above the twelfth rib 5 cm. from

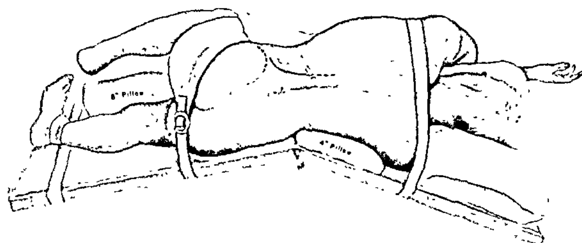


Fig. 99. Lateral-oblique position of lumbar or thoracolumbar sympathectomy.
The incision for removal of the lumbar ganglia is shown by the continuous line The added line of dashes extending up over the three lower ribs indicates the longer incision required for thoracolumbar sympathectomy.

its spinous process and be carried downward and laterally in a gentle curve to the middle of the iliac crest.

It is first necessary to divide the fibres of the latissimus dorsi and then to open the lumbar fascia which unites the three abdominal muscles to the sacrospinalis and quadratus lumborum muscles. The retroperitoneal space is thereby entered. In thick, short-coupled individuals it is best to divide the posterior fibres of the external oblique laterally several centimeters along the iliac crest. With care not to injure the first lumbar nerve, the peritoneum and renal fascia, together with the ureter, are stripped off the quadratus lumborum and psoas muscles. This exposes the vena cava on the right, or aorta on the left, and the anterolateral surface of the bodies of the lumbar vertebrae to which the psoas is attached (Fig. 100). The lumbar chain lies

pain usually requires removal of the first lumbar ganglion and a bilateral resection is almost never required.

C. THORACOLUMBAR GANGLIONECTOMY AND SPLANCHNICECTOMY

Combined removal of the lower thoracic and lumbar ganglia, together with the major, minor and least splanchnic nerves, is advisable for interruption of certain varieties of abdominal pain. The relationship of these structures is illustrated in Figure 101. In cases of intractable renal and ureteral pain, relief is more certain and more likely to be permanent if this is added to simple denervation of the renal pedicle. In addition, this approach greatly improves the exposure of the kidney. While the first lumbar ganglion can often be included in a supradiaphragmatic resection, this can by no means be counted on and it is as yet far from certain that some pain fibres from the kidney and ureter do not enter the cord as low as the second lumbar rami.

Endotracheal anaesthesia is used in order to maintain adequate pulmonary inflation if the pleura is opened. The patient is placed on his side in the same position as shown in Figure 99. A 4-inch cushion supports the chest to take weight off the under arm and prevent compression of the axillary vessels and nerves. The upper thigh and knee are flexed and supported by an 8-inch pillow placed between the legs to relax the psoas muscle. A webbed belt and broad bands of adhesive will hold the patient in the correct position. The table is then broken in the middle in order to gain the greatest possible space between ribs and iliac crest.

The paravertebral incision is a longer one than that used for lumbar ganglionectomy, starting at the level of the tenth rib and continuing parallel and 5 cm. lateral to the spinous processes down to the midlumbar region, where it is curved laterally to the middle of the iliac crest. To expose the twelfth rib fibres of the trapezius, latissimus dorsi, and serratus posticus inferior muscles are cut. Between the twelfth rib and iliac crest the lumbar fascia is exposed. The central articulation of the twelfth rib with its transverse process is next uncovered by dividing the costal insertions of the sacrospinalis muscle and drawing it toward the midline. The entire twelfth rib, unless it is an unusually long one, is then resected, or the rib may be made to serve as a self-retaining retractor. For this purpose it is freed from its bed and bent slowly backward on its central articulation 90 degrees, in which position it is held by a loop of gauze clamped to the drapes with a towel clip. Its projecting end is cut off. After being used in this way, the central remnant of the rib should be resected at the time of closure.

The next step is to divide the lumbar fascia, separate the abdominal from the posterior longitudinal muscles, and mobilize the kidney, ureter, and

to tilt the table towards the surgeon, in order to gain a more direct view of the vertebral bodies to which the chain is attached.

Using tufts of gauze grasped in long curved forceps the surgeon gently pushes aside the fat and lymphatics at the inner angle of the incision to expose the second or third lumbar ganglia. These will be found under the lateral edge of the vena cava or aorta adhering to the bodies of the corresponding vertebrae. Care is necessary, especially on the right side, not to tear bridging vertebral veins, which at times pass over the sympathetic trunk. Once the trunk is hooked up and mobilized by clipping and cutting its anchoring rami, it should be cut off just above the point where it passes beneath the common iliac vessels. Its rostal end can then be grasped in a forceps and the chain of ganglia freed upwards towards the crus of the diaphragm.

When operating for local painful lesions associated with vasospasm of the foot, it is not necessary to resect the chain higher than its second ganglion, but in cases of causalgia due to injury of the sciatic nerve in the thigh it is important to follow it higher. For a good view of the upper angle of the incision a lighted retractor is helpful. The chain will be found to disappear under cover of the medial crus of the diaphragm, which must be divided in order to expose the first lumbar ganglion. When the lesion involves the sciatic nerve in the buttock, Mayfield and Devine (1945) have recommended carrying the ganglionectomy upwards to include the twelfth thoracic ganglion. It may be possible to do this by dividing the diaphragm from below, or it may be preferable to use the procedure described in the following section. After the ganglionectomy has been completed the table should be straightened and flattened to permit an easy approximation of the muscles, fascia, and skin.

An alternative method, which we have not often used, but which may seem preferable to some surgeons, is the anterior muscle-splitting incision. This other extraperitoneal approach was devised by Pearl (1937) and has been modified and very well described by Shumacker (1948C). An oblique incision is made from the tip of the eleventh rib to the lateral edge of the rectus, and the three lateral abdominal muscles divided in the plane of their fibres and retracted. The peritoneum is peeled laterally from the inner surface of the transversalis, quadratus lumborum, and psoas muscles, retracting the peritoneum with its contents towards the midline to expose the paravertebral gutter and the lumbar chain. As the operation is performed with the patient supine, bilateral resection of the lumbar chains can be carried out through two incisions at a single stage. It is well adapted for exposure and resection of the lower lumbar chain, but should not be employed when the resection is to include the first lumbar ganglion. We have not described the tèchnique in detail because lumbar sympathectomy for

peritoneum from the quadratus lumborum and the psoas. This is done by blunt finger dissection, with special care to free the space under the diaphragm down to its medial arcade. At this stage the twelfth intercostal and first lumbar nerves are encountered as they arch across the incision. If possible, it is best to preserve them intact, but the surgeon must bear in mind that excessive traction on these structures may lead to severe postoperative radicular pain. Sometimes it is better to cut a nerve than to preserve it after it has been overstretched.

The pleura is separated with the fingers from the lateral surface of the lower thoracic vertebrae, using particular care to free the central attachment of the diaphragm down to its medial arcade. The pleural cavity may be opened inadvertently at this stage of the procedure, but with an intratracheal tube and an experienced anaesthetist this makes little difference.

Once the lateral surface of the vertebral column has been freed of pleura above the diaphragm up to the ninth rib and of the renal fascia and peritoneum below down to the level of the iliac crest, the diaphragm can, if necessary, be divided down to its medial arcade, leaving a narrow cuff of muscle attached to the vertebrae for subsequent suture. This step is facilitated by inserting the index finger of the left hand on one side of the arcuate ligament and the middle finger on the other, then cutting the muscle fibres between them with a scissors. This gives a wide exposure of the sympathetic chain and splanchnic trunks both above and below the diaphragm (Fig. 101). If the exposure of the sympathetic trunks above and below the diaphragm is satisfactory, as is often the case, there will be no need to cut it.

The next step is to proceed with the actual neurectomy. The major splanchnic nerve, which lies anterior and medial to the chain of ganglia, is elevated on a nerve hook and freed by blunt dissection. It is divided a centimeter or two below the diaphragm, where it expands into the coeliac ganglion. The distal end is clamped with a dural clip and cut. The dissection is then carried upward and is facilitated by the use of lighted retractors. The minor and least splanchnic nerves are usually seen running parallel to the major trunk and are resected at the same time. The major splanchnic nerve is clipped and cut above the level of the ninth rib. When the diaphragm has not been cut across, these structures are freed and drawn out through the medial arcade.

By the time the splanchnic trunk has been resected the more superficial chain of thoracic ganglia should be clearly in view as it loops over the heads of the ribs. The chain is picked up on a nerve hook and freed by cutting the communicant rami which anchor the ganglia to the intercostal nerves. These are first secured with dural clips in case an intercostal vessel be severed by mistake. When the chain has been freed to a point above the tenth rib and cut off, the dissection is carried downward beneath the dia-

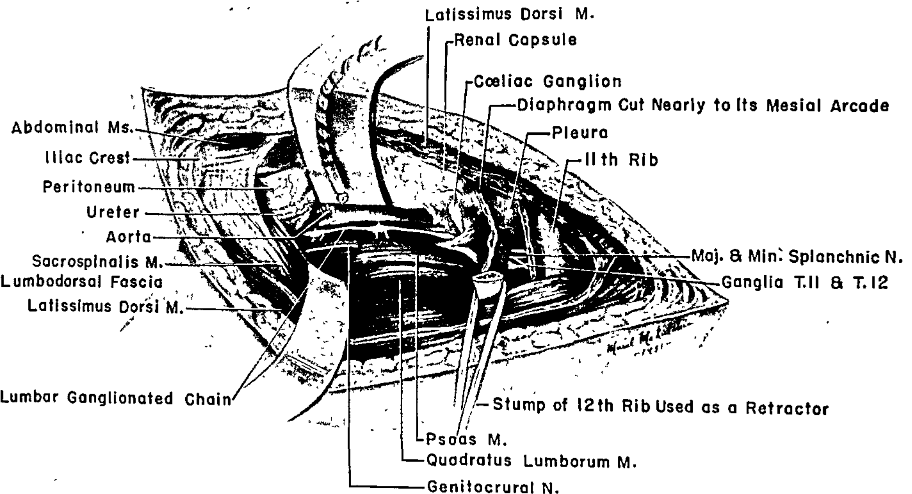


Fig. 101. Thoracolumbar sympathetic ganglionectomy and splanchnicectomy.
The patient is lying on his right side in this case and the surgeon is working in the left thoracic cavity.

this wide exposure it is a very simple matter to mobilize the kidney and develop its pedicle by blunt dissection. When cleaned of fat the fine plexus of nerves which surrounds the renal artery and veins is clearly seen. The nerves are easily picked up and resected over a length of several centimeters. This procedure alone may relieve pain arising from the kidney or upper ureter, but we have felt it safer to remove the lower thoracic and upper lumbar ganglia together with the splanchnic trunks at the same time. Removal of these ganglia is much more certain to ensure a complete interruption of afferent pathways and to prevent regeneration of the minor and least splanchnic trunks and other accessory connections through the upper lumbar ganglia.

D. LOWER THORACIC GANGLIONECTOMY AND SPLANCHNICECTOMY: SUPRADIAPHRAGMATIC OPERATION OF PEET

For most varieties of persistent pain in incurable disease of the upper abdominal viscera (postoperative pain from the biliary tract, pancreatic fibrosis with calcification, etc.), sympathetic denervation need not be carried beneath the diaphragm. The supradiaphragmatic sympathectomy, developed by Peet for treatment of hypertension, is the best procedure for this purpose. If this operation needs to be carried out bilaterally, this can be done in one stage with two teams operating simultaneously in about an hour and a half.

Under intratracheal ether-oxygen anaesthesia the patient is placed in the prone position with chest and pelvis supported on hard, square-sided cushions, so that abdominal respiratory movements are free. Unilateral or bilateral paravertebral incisions 15 cm. in length are made 5 cm. from the line of spinous processes and centered over the eleventh rib. When the muscles have been cut and retracted the central 5 cm. of this rib is resected. From this stage on the operative technique differs in no essential manner from the intrathoracic portion of the more extensive thoracolumbar resection. The pleura is freed widely from the medial portion of the diaphragm, the lower thoracic vertebrae, and the costal articulations as high as the finger can reach (to about the eighth rib). With a lighted retractor, the ganglionated chain is now easily seen as it runs over the costovertebral articulations (Fig 103). The major splanchnic trunk, which is more deeply situated on the anterolateral portion of the vertebral bodies, can be picked up most readily where it passes through the medial arcade of the diaphragm With this exposure there should be no difficulty in resecting the sympathetic chain from its ninth to eleventh ganglia, which includes the origin of the minor splanchnic nerve, and some 7 cm. of the major splanchnic. A resection of this extent is usually sufficient to prevent regeneration, but with a

phragm. It should include the minor and least splanchnic nerves which arise from the lowest thoracic ganglia (Fig. 102).

Following this complete removal of the sympathetic chains and splanchnic nerves from the lower thorax, the upper lumbar ganglia may be resected. Their exposure is much easier with the patient on his side than in the prone position, since the sympathetic chain swings to a more anterior position between the twelfth thoracic and first lumbar vertebrae. The technical steps used to resect the lumbar ganglia differ in no way from those described in

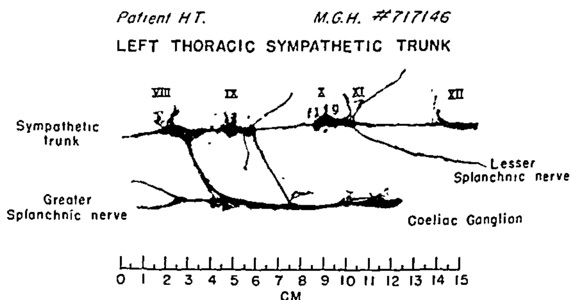


Fig. 102 Thoracolumbar sympathectomy.
Photograph of specimen after limited resection of thoracolumbar ganglia and splanchnic nerves for relief of pain arising from upper abdominal viscera.

the preceding section. In the case of a unilateral thoracolumbar denervation there is no danger of interfering with the ability of the male to ejaculate, a complication which may lead to serious complaints when this operation is done bilaterally for hypertension (Whitelaw and Smithwick, 1951).

When the neurectomy has been completed the fibres of the diaphragm, if divided, are sutured with cotton or silk. The pleura, which has been widely detached, tends to remain collapsed. To secure re-expansion of the lung a catheter should be left in the retropleural space and another within the pleura, if it has been opened. The anaesthetist is requested to apply increased intratracheal pressure as the muscles and fascia of the back are sutured. All air is then removed by suction with a large syringe and the catheter withdrawn. The skin is closed with interrupted sutures of fine silk.

When this operation is being performed for pain arising from the kidney or ureter it is best to resect the nerves in the renal pedicle as well. With

this wide exposure it is a very simple matter to mobilize the kidney and develop its pedicle by blunt dissection. When cleaned of fat the fine plexus of nerves which surrounds the renal artery and veins is clearly seen. The nerves are easily picked up and resected over a length of several centimeters. This procedure alone may relieve pain arising from the kidney or upper ureter, but we have felt it safer to remove the lower thoracic and upper lumbar ganglia together with the splanchnic trunks at the same time. Removal of these ganglia is much more certain to ensure a complete interruption of afferent pathways and to prevent regeneration of the minor and least splanchnic trunks and other accessory connections through the upper lumbar ganglia.

D. LOWER THORACIC GANGLIONECTOMY AND SPLANCHNICECTOMY: SUPRADIAPHRAGMATIC OPERATION OF PEET

For most varieties of persistent pain in incurable disease of the upper abdominal viscera (postoperative pain from the biliary tract, pancreatic fibrosis with calcification, etc.), sympathetic denervation need not be carried beneath the diaphragm. The supradiaphragmatic sympathectomy, developed by Peet for treatment of hypertension, is the best procedure for this purpose. If this operation needs to be carried out bilaterally, this can be done in one stage with two teams operating simultaneously in about an hour and a half.

Under intratracheal ether-oxygen anaesthesia the patient is placed in the prone position with chest and pelvis supported on hard, square-sided cushions, so that abdominal respiratory movements are free. Unilateral or bilateral paravertebral incisions 15 cm. in length are made 5 cm. from the line of spinous processes and centered over the eleventh rib. When the muscles have been cut and retracted the central 5 cm. of this rib is resected. From this stage on the operative technique differs in no essential manner from the intrathoracic portion of the more extensive thoracolumbar resection. The pleura is freed widely from the medial portion of the diaphragm, the lower thoracic vertebrae, and the costal articulations as high as the finger can reach (to about the eighth rib). With a lighted retractor, the ganglionated chain is now easily seen as it runs over the costovertebral articulations (Fig 103). The major splanchnic trunk, which is more deeply situated on the anterolateral portion of the vertebral bodies, can be picked up most readily where it passes through the medial arcade of the diaphragm. With this exposure there should be no difficulty in resecting the sympathetic chain from its ninth to eleventh ganglia, which includes the origin of the minor splanchnic nerve, and some 7 cm. of the major splanchnic. A resection of this extent is usually sufficient to prevent regeneration, but with a

little patience and dissection with cotton on an applicator, one can usually extend the retropleural dissection caudally into the muscular attachment of the diaphragm to remove the twelfth thoracic ganglion. This operation is less likely to be followed by postoperative neuralgia, which may be troublesome after the transdiaphragmatic thoracolumbar dissection, in which the twelfth thoracic and first lumbar nerves are exposed to considerable trauma.

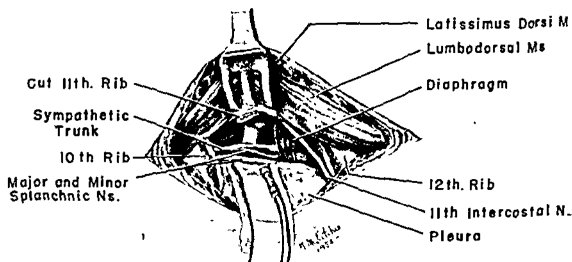


Fig 103. Retropleural supradiaphragmatic sympathectomy and splanchnicectomy
The patient is lying face down in this case and the surgeon is working in the left thoracic cavity.

E. RESECTION OF SUPERIOR HYPOGASTRIC PLEXUS (PRESACRAL NEURECTOMY)

Presacral neurectomy is a valuable method for controlling the pain of idiopathic dysmenorrhoea when all other methods have been tried and when exploratory laparotomy fails to reveal a correctable cause. It may also be combined with uterine suspension or plastic procedures on the tubes and ovaries. This operation has few other uses. Uterine carcinoma is not painful until the disease has extended into the broad ligaments and involved the lumbosacral plexuses. As afferent fibres from the bladder, cervix and prostate run entirely in the sacral rami, resection of the superior hypogastric plexus is unfortunately useless in such painful conditions as tuberculosis of the bladder. It has been claimed that the operation has a limited value in chronic interstitial cystitis (Hunner's ulcer) through improvement of blood supply and relaxation of spasm at the vesical neck, but the results in our hands have been far from satisfactory. Pain from the testes and ovaries also is not influenced by excision of these nerves, as the impulses traverse the spermatic and ovarian plexuses.

The superior hypogastric plexus is a caudal extension of the preaortic nerves (Fig. 104A). There is not, as the name implies, any distinct presacral nerve, but a plexus made up of a variable number of rami which pass down over the bifurcation of the aorta with additional filaments from the fourth lumbar ganglia emerging from beneath the common iliac vessels. These rami combine and separate into two divisions which terminate in the inferior hypogastric plexus behind the bladder (Elaut, 1932). Aside from their role as sensory nerves to the body of the uterus, these rami regulate the blood supply of the pelvic viscera and the motor control of the vasa deferentia, seminal vesicles, and prostate. Excision of the plexus therefore

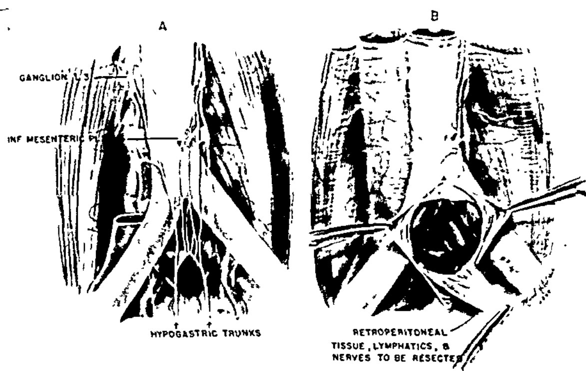


Fig. 104 Presacral neurectomy.
From White, 1946A. Courtesy, J. B. Lippincott Co., Philadelphia.

sterilizes the male, who can no longer ejaculate, but it does not make him impotent nor deprive him of the sensation of orgasm (Whitelaw and Smithwick, 1951). In the female excision of the plexus results in no inconvenience of any sort. The operation may precipitate a brief episode of intermenstrual bleeding, and subsequent childbirth is likely to be painless until the perineum is stretched in the final stage of labour.

The operation is performed in pronounced Trendelenburg position. A left paramedian incision is centered on the umbilicus and the coils of intestine drawn gently into the upper abdomen and held there with warm packs of moist gauze. This gives a clear exposure of the aortic bifurcation down to the origin of the hypogastric vessels. The posterior peritoneum is incised

over this extent in the midline. The cut edges are then retracted with silk stay sutures and the retroperitoneal areolar tissue and fat wiped off the lower end of the aorta. The descending plexus of nerves is thereby exposed. The individual strands should next be freed and gathered together on a nerve hook. These can in turn be grasped in a large haemostat, ligated, and cut centrally (Fig. 104B).

Given a good exposure, it is a simple matter to follow the plexus caudally by dissection with tufts of gauze grasped in a long forceps. This must be carried downward some 5 cm. until a triangle has been cleared with its sides marked by the common iliac arteries and the base by a line drawn between the origin of the two hypogastric arteries. When carried to this point the dissection should include the lowest rami leaving the sympathetic chains from the fourth lumbar ganglia, which pass beneath the iliac vessels. Elaut's anatomical description has shown that at times some fibres may run laterally in the pedicle of the inferior mesenteric artery. These must be searched for or the resection may be incomplete and ineffective. Care must also be taken not to traumatize the common iliac vein on the left side, as it emerges from beneath the aortic bifurcation and lies medial to the artery. When the entire superior hypogastric plexus has been elevated and freed it should again be ligated securely before cutting it off below. Included in the plexus are a large number of pelvic lymphatics and occasional small branches of the sacral artery. After careful scrutiny of the dissected area, to make sure that there are no remaining filaments of nerve or bleeding points, the posterior peritoneum is resutured. The gauze packs are then removed, the table flattened, and the abdominal incision closed.

PART III

INTRODUCTION

THESE FINAL CHAPTERS contain an account of the neuralgias, pain in malignant conditions and in forms of visceral disease which are resistant to either medical treatment or direct surgical attack, but in which pain is the outstanding complaint. Neurosurgical methods for interruption of the afferent pathways are taken up in detail. Conditions such as temporal arteritis or sciatica, in which relief can be obtained by direct attack on the lesion itself, are not included.

Measures for relief of pain must not only be consistently effective but lasting. Return of pain coincident with regeneration of sensory fibres or by conduction through accessory pathways is an important consideration. This is unfortunately a rather frequent occurrence, not only after neurectomy but also after extensive sympathetic ganglionectomy and splanchnicectomy. Even after what at first seems to be a satisfactory transection of the spinothalamic tract, pain may reappear within a period of months, either through fall of the initial adequate level of analgesia or as a result of extension of the disease itself.

As a result, short-term observations are of little value and at times actually misleading in the evaluation of the various surgical techniques. As a general rule freedom from pain postoperatively for a period of over a year can be taken as a successful result, but in one of our most satisfactory cases of sympathectomy for angina pectoris pain recurred on one side after a period of three years, coincidentally with return of sweating in the arm and hand. Another patient with a painful phantom arm after amputation had a perfect result for an equally long period following cordotomy only to have the disagreeable sensation of his missing hand return after a late change from analgesia to high-grade hypalgesia. We have made every effort to obtain late observations and, although many early results are included in the statistics which follow, we must advise that the outcome in all patients observed for only a short period be taken with the proverbial grain of salt. Whenever we have had a sufficient number of cases to be statistically significant, we have preferred not to report others in which operation was performed later than the end of 1948.

CHAPTER XII

NEURALGIAS OF THE PERIPHERAL NERVES: PAINFUL NEUROMATA, AMPUTATION STUMPS, PHANTOM LIMBS, CAUSALGIA, AND POST-TRAUMATIC DYSTROPHY

In this chapter are included the common painful conditions arising from lesions of peripheral nerves which require neurosurgical intervention for relief. These, although of widely different etiology, have much in common. Always a problem to the military surgeon and neurosurgeon, they are a frequent cause of concern to orthopaedists and insurance doctors as well.

A. CLASSIFICATION OF PERIPHERAL NEURALGIAS FOLLOWING TRAUMA AND AMPUTATION*

Interest was first focused on the elusive problems of pain after wounds of peripheral nerves by the classical description of Mitchell, Morehouse, and Keen (1864) in a book based on their experience with these injuries during the War between the States. After such a promising early start, it is surprising that more was not found out about these lesions during the periods of peace and recurrent wars which led up to the recent conflicts. Since the First World War the pioneer work of Leriche, summarized in the latest edition of his book on pain (1949), has been a constant stimulus. Effective methods for treating most of these sufferers have evolved gradually and have finally been put on a fairly satisfactory basis by the combined work of American and British military surgeons during World War II. With the great number of amputations and injuries of peripheral nerves which reached our base hospitals from overseas, these sources of persistent pain are certain to be a major problem for years to come.

1. Underlying Pathological Factors

The common injuries which may lead to persistent pain are amputations and partial or complete wounds of the peripheral nerve trunks. Concomitant injury of a large artery may also occur, but as this complication

*A portion of this section has been taken from a previous article on "Painful injuries of nerves and their surgical treatment," which appeared in the *American Journal of Surgery*, 1946, 72:468-488 We wish to express our thanks to the editor for his kind permission to reproduce this material.

is not present in the majority of cases it cannot play any important role. Faulty regeneration of injured nerves, sepsis, and resultant formation of scar tissue appear to constitute the underlying factors which give rise to painful stimuli, although some further factor is necessary to explain the onset of burning pain in the hand or foot which sometimes develops within a few hours after wounding.

Recent determinations of the threshold for "burning" as contrasted with "pricking" pain performed by Bigelow, Harrison, Goodell, and Wolff (1945) have demonstrated that the slowly conducting, poorly myelinated "C" fibres carry disagreeable forms of sensation. The "paradoxical pain" of the peripheral neuropathies is the expression of a defect in the nerve in which the threshold for "burning pain" is depressed, so that ordinary innocuous stimuli are perceived as painful, whereas the threshold for "pricking pain" in the larger myelinated fibres is elevated.

Foerster (1927A) was one of the first to suggest that stimulation of an isolated "pain point" evoked the special abnormal feelings for which he proposed the term "hyperpathia." The "hyperpathic" response from the individual pain points is said by him to have these characteristics: 1) a high threshold; 2) a long latent period between stimulus and response; 3) then explosive appearance of a peculiarly unpleasant pain which is— 4) localized poorly; 5) irradiates to a wide area; 6) outlasts the stimulus; 7) causes vigorous protective movements with vasomotor and vegetative reactions, and 8) reduces two-point discrimination. From his clinical observations Foerster thought that the hyperpathic response became intensified as long as new pain points alone were being reinnervated following injury to a peripheral nerve. Only as soon as other sensory modalities such as touch and pressure could be appreciated did the hyperpathic characteristics start to recede.

More intensive studies of sensation during regeneration of cutaneous nerves and histologic examination of partially reinnervated skin at various stages have failed to substantiate Foerster's hypothesis, and the production of disagreeable over-response has been explained by the Oxford investigators Weddell, Sinclair, and Feindel (1948) on the basis of incomplete regeneration of the cutaneous sensory network for pain alone. As summarized by Le Gros Clark (1947), the terminal network of sensory fibres in normal skin* "overlap and interweave in a most complex manner, so that ordinarily a painful stimulus affects a number of adjacent terminals simultaneously. If a single pain fibre is stimulated, however, it gives rise to a painful sensation of a particularly disagreeable and intolerable character."

*Clark, W.E. LeG.: *Anatomical pattern as the essential basis of sensory discrimination.* (Forty-ninth Robert Boyle Lecture, Oxford University, May 29, 1947.) Blackwell Scientific Publications, Oxford, 1947.

While the exact physiological explanation of this altered type of sensation (dysaesthesia) remains uncertain, Le Gros Clark believes that it is related to "the particular pattern of excitation aroused in the central nervous system by the arrival of single instead of multiple sensory impulses from the same sensory spot." He adds, "there may also be a temporal factor involved, for it is well known . . . that if impulses from the same sensory spot arrive at the central nervous system at different times, the activity induced by the first impulse modifies, and may itself be modified by, the effects of oncoming volleys." This theory, although unsupported by crucial experiment, is perhaps a more satisfactory explanation for the phenomenon of over-response than Trotter's earlier theory (1926) that pain in partial regeneration is due to a lack of insulating myelin.

A likely contributory factor to the production of pain in neuromas is anoxia, either from local scarring or from widespread vasoconstriction. R. Lorente de Nó (personal communication, 1944) has shown that a nerve made anoxic fires off repetitive stimuli, which suggests that impaired circulation may be a fundamental source of painful stimulation. Still another possible explanation is an accumulation of painful metabolites in the neuroma. Lewis (1942) postulated that there is a centrifugal discharge from the point of nerve injury which liberates hypothetical metabolic substances in the tissues, giving rise to pain as well as cutaneous changes. He postulated that the favourable effect of sympathectomy is brought about by the increase in circulation which washes these substances away. If this were true, pain in causalgia and other related painful states should be increased by a tourniquet. We have investigated this possibility and found that it is not true.

In addition to the possible roles of vasospasm and local ischaemia in the production of these painful states, Doupe, Cullen, and Chance (1944) have suggested another factor associated with overactivity of the sympathetic nervous system. They ascribe the peculiar qualities of causalgic pain to direct cross stimulation of sensory fibres by efferent sympathetic impulses at the point where the nerve trunk is injured. This theory deserves serious consideration, as in certain stages in the evolution of many of these painful syndromes there may be an actual vasodilatation. It furnishes an explanation, not only for the increase in pain which so characteristically takes place in a very hot or cold environment, but also for the peculiar exacerbations during any form of emotional excitement and, in some extreme instances, during everyday visual and auditory stimuli. Burning pain in causalgia and in certain other conditions occurs in direct relationship to the tonic vasomotor, sudomotor, and pilomotor discharge over the sympathetic efferent pathways.

Striking experimental corroboration of the hypothesis that causalgic pain

is produced through short-circuiting of efferent sympathetic impulses to sensory somatic fibres at the point of nerve injury has been reported by Walker and Nulsen (1948). In the course of preganglionic sympathectomies in man pull-out electrodes were applied to the decentralized upper thoracic sympathetic ganglia. On their subsequent electrical stimulation the fully conscious patients reported a variety of sensations. As might be expected, the majority of these were referred to the local area in the back or the distribution of the corresponding intercostal nerves. Pain was referred to the arm and hand in only the three individuals who had suffered from causalgia. In each of these there was a characteristic and reproducible pattern. Tingling, burning pain developed slowly with a latent period of four to 20 seconds (too slowly for direct central conduction) and usually paralleled the pilomotor response. There was often a low grade ache which persisted for as long as 24 hours after stimulation. These observations all point to the fact that the role of the sympathetic fibres in causalgia is connected with the discharge of irritant motor impulses and not to direct conduction of pain.

In corroboration of this theory of sympathetic activation of sensory fibres, it has been shown by Katz and Schmitt (1940) that in certain circumstances efferent nerve impulses can alter the excitability of adjacent sensory axones. Granit, Leksell, and Skoglund (1944) have given direct experimental proof of such cross-stimulation between motor and sensory fibres at a point of nerve injury by recording with the cathode ray oscillograph an afferent discharge from the sensory root which takes place when the motor root is stimulated. In the absence of any injury to the peripheral nerve no such returning discharge was observed. They concluded that the small, poorly myelinated pain axones of the C-group should be especially susceptible to "fibre interaction," and point out that this is a simple explanation for some of the symptoms of causalgia. The theory of Doupe and his co-workers assumes that the activating impulses come from the sympathetic vasomotor, pilomotor, and sudomotor discharge, which is increased by cold or emotion

Pertinent evidence from another angle is the fact that causalgia is reduced in a quiet, stable environment and during sleep, when the tonic hypothalamic discharge is greatly diminished. Despite the opinion of certain writers, summarized on pp. 87, 363, we are convinced that there are usually no afferent fibres from the limbs incorporated in the sympathetic trunks which can play a direct role in the central conduction of pain.

2. Painful Syndromes

a. Painful over-response (dysaesthesia) in areas of incomplete sensory recovery.—This condition is associated with neuromas in continuity when

there is partial injury to a nerve or incomplete recovery after its transection and suture. Any of the larger nerves in the arm or leg may be involved, most often the median, ulnar, or tibial. Oversensitivity to sensory stimuli and paraesthesiae in variable degrees of intensity are then manifest. When tested with an algesiometer or von Frey hairs, the threshold both to pin-prick and touch is usually elevated over the entire peripheral area supplied by the nerve, but the sensation has a peculiarly disagreeable tingling and burning quality. The abnormal appreciation of pain and touch is probably due to an incomplete reconstitution of the complex network of cutaneous sensory axones, as described so well by the Oxford school of anatomists (see p. 361).

We have seen numerous examples of this condition in our review of the wartime peripheral nerve injuries carried out at the Massachusetts General Hospital for the National Research Council and the Veterans Administration. Herz and Yahr (1950) have published an excellent description of their findings in a similar study conducted in New York. Some degree of over-response was present in 20 per cent of the 500 veterans whom they examined three to six years after nerve suture. In the majority the discomfort has subsided with time and better recovery of function or overlap from adjoining sensory nerves. The symptoms vary in intensity, at times being only a source of mild annoyance when the skin is touched, at others a cause of total incapacity, especially when the median or tibial nerves are involved to the extent of making it difficult to exert pressure between the thumb and forefinger or to bear weight on the sole of the foot. This condition is often mistakenly referred to as causalgia, but the area of discomfort is limited to the terrain supplied by the injured nerve and the symptoms are not characteristically intensified by cold or emotional stimuli. The syndrome has proven very resistant to simple neurosurgical procedures such as neurolysis or excision of a neuroma in continuity and suture. Occasionally, however, the discomfort becomes much more intense in the cold and, under such circumstances, we have recently found that relief may be obtained by sympathectomy (see below, p. 388). Failing this simple solution, anterolateral cordotomy is the only alternative that carries a reasonable chance of success.

b. **Painful neuromas.**—End-bulb neuromas, which can often be palpated in an amputation stump or scar over an injured nerve, can produce exquisite local tenderness and, in addition, cause ill-defined disagreeable sensations over wide areas. Although the local tenderness may be relieved by resection of the end-bulb and effective measures to prevent its reformation, various forms of pain may persist: burning dysaesthesia, deep aching sensations with central radiation, and at times crises of lancinating pain. Why most neuromas should be painless and others the cause of long-lasting torture is altogether unknown. These phenomena cannot be explained en-

tirely on the basis of an idiosyncrasy on the part of the individual patient (such as a low threshold for pain), because in certain individuals with multiple nerve injuries or amputations only a single neuroma will become painful (K. E. Livingston, 1945).

Why is removing the pain-producing neuroma so seldom successful? A new neuroma may form, but sometimes the pain is not even temporarily relieved or recurs sooner than the peculiar end-bulb can be reproduced. This and the fact that more proximal crushing or chemical destruction by infiltrating the nerve trunk with alcohol fails to give relief have forced investigators to predicate a central extension of the pain mechanism. Mitchell, Morehouse, and Keen (1864) described an ascending neuritis, but examinations of sections of nerves removed during therapeutic neurectomies have not shown any histological alteration. Just what the proximal mechanism may be we are at a loss to explain. In our hands it has invariably ceased after anterolateral cordotomy when analgesia has persisted at an adequate level. This observation, which we have made in 10 cases, would seem to disprove the hypothesis that pain of this sort may be propagated by higher reflex mechanisms in the brain.

c. Causalgia.—The classical causalgic syndrome described by Mitchell, Morehouse, and Keen (1864)* is most often seen after partial injuries of the median, ulnar, and sciatic nerves. Many good descriptions of this condition have been published in the last few years, of which the recent review by Shumacker (1948*A*) is an outstanding summary of the clinical picture and the development of successful therapy in World War II.**

Causalgia characteristically develops after penetrating wounds of peripheral nerves. Usually the injury to the nerve trunk is a partial one (Fig. 105A). A peculiar burning hyperpathia*** involves the hand or foot, and is most pronounced in the digits, palm of the hand, or sole of the foot. The skin soon becomes shiny and glossy smooth, at times scaly and discoloured (Fig. 105A), with tapering fingers and long, curved nails. The pain and dysaesthesia are frequently not restricted to the area of sensory defect, but the latter is often difficult to demarcate because no accurate neurological

---

*Sir James Paget (1864) has also been mentioned as co-discoverer of the causalgic syndrome. In a lecture delivered at St. Bartholomew's *Hospital* on February 6, 1864, he described some cases of "local paralysis" with "glossy fingers" which "are always associated with distressing and hardly manageable pain." His cases we believe were examples of plexus avulsion and, beyond the pain and trophic disturbances, did not have the characteristic features of causalgia which were described later in the *same year* by Mitchell, Morehouse, and Keen. Some even earlier cases have been recorded by Sir James Paterson Ross (1932).

**The monograph of Mayfield (1951), published recently, gives an even more thorough and up-to-the minute review.

***We have used the term hyperpathia in conformity with Foerster's original definition (see p. 361).

examination is possible during the acute phase. Sudomotor and vasomotor disturbances are the rule. According to de Takats (1945), there is invariably a vasodilatation, which he ascribes to the antidromic vasodilator action of the posterior root fibres (Bayliss, 1901). De Takats goes so far as to state that this response is a point in the differential diagnosis between these

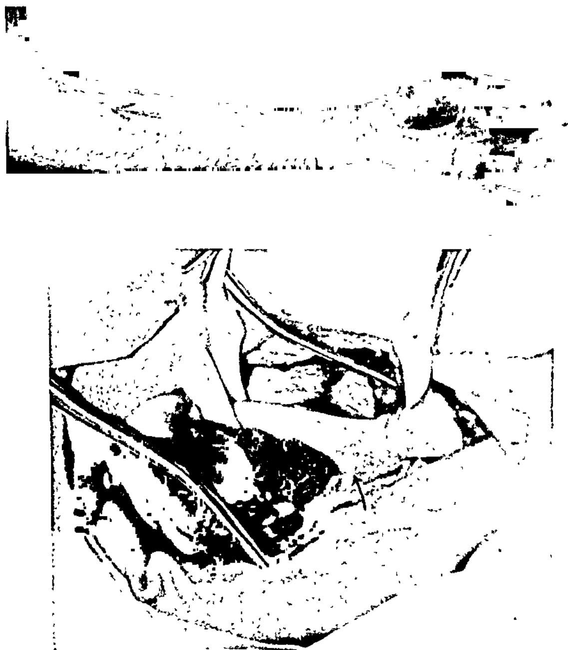


Fig. 105. Causalgic syndrome: Typical lesion following partial injury of median nerve by rifle bullet (Patient 24, Table XVI).

A (*upper*). Photograph showing trophic changes in skin and tapering of fingers in area innervated by median nerve. Arrow points to bullet wound.

B (*lower*). Appearance of median nerve at preliminary exploration. Note filmy cicatricial adhesions and lateral neuroma at arrow.

From White: *Am J Surg*, 1946B, by permission of the editor.

painful states and hysterical paralysis, in which the hand is generally cool. In Mayfield and Devine's (1945) carefully observed series they found three individuals with cold and nine with hot extremities, whereas in our 14 Naval and Marine Corps patients (White, Heroy, and Goodman, 1948), who were hospitalized at a later date after wounding, the extremities were always considerably cooler than normal.

Excessive autonomic activity in emotional states results in profuse sweating of the palms and soles, and at times warm but more often abnormally cool extremities. While de Takats (1945) has shown by oscillometric tracings that the vasodilator response is unilateral, the later vasoconstriction and abnormal sweating usually involve the other extremities, although possibly to a lesser degree. It is quite possible that cutaneous vasodilatation is the characteristic condition in the early phase of causalgia, but after a time, at least, the opposite is frequently true. Everyone who has studied the condition has been impressed by the profuse sweating of the involved hand or foot, but generalized nervous sweating of the hands and feet is a common phenomenon in wounded men, especially when pain is a prominent feature.

In the typical severe forms of causalgia the cutaneous dysaesthesia may become so intense that the patient cannot bear contact with clothing or even draughts of air. The extremity is kept constantly protected and immobile and must often be wrapped in a cloth or moistened with lukewarm or cool water. The individual so afflicted is most comfortable if the extremity is kept at a neutral temperature. In India Slessor (1948) found that causalgic symptoms became particularly intense when the temperature climbed over 100 degrees and that none of his patients could tolerate the direct rays of the sun. We observed identical responses on exposure to cold during the winter of 1945. The sufferer becomes more and more a nervous recluse and seeks to withdraw himself from the noises and activity of an open ward. He cannot listen to tense or annoying radio programs or sit through an exciting movie. Any disagreeable stimulus, such as tickling or scratching the skin, or a hypodermic injection in any part of the body, produces unbearable pain in the affected extremity. These are characteristic differentiating features of true causalgia.

It has often been claimed that the condition is most likely to result after nerve wounds in which there is associated sepsis or arterial injury. The latter is certainly not an important feature, and most of the recently reported cases have not been preceded by major wound sepsis. The best argument against this premise is the frequent rapid onset of the pain, which so often develops as soon as the patient has recovered from the initial shock of his wound.

The outstanding reports from the recent war have added over 600 cases,

examination is possible during the acute phase. Sudomotor and vasomotor disturbances are the rule. According to de Takats (1945), there is invariably a vasodilatation, which he ascribes to the antidromic vasodilator action of the posterior root fibres (Bayliss, 1901). De Takats goes so far as to state that this response is a point in the differential diagnosis between these

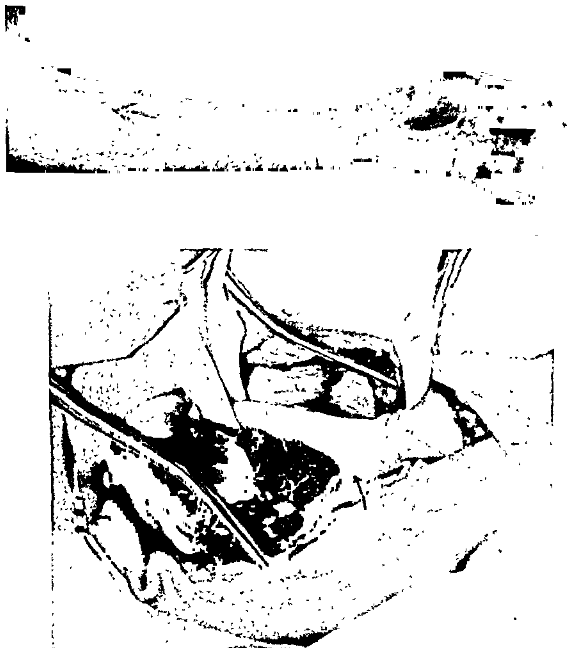


Fig 105. Causalgic syndrome· Typical lesion following partial injury of median nerve by rifle bullet (Patient 24, Table XVI).

A (*upper*). Photograph showing trophic changes in skin and tapering of fingers in area innervated by median nerve. Arrow points to bullet wound.

B (*lower*). Appearance of median nerve at preliminary exploration. Note filmy cicatricial adhesions and lateral neuroma at arrow.

From White· *Am. J. Surg*, 1946B, by permission of the editor.

TABLE XIV

PUBLISHED CASES OF CAUSALGIA IN WORLD WAR II AND ITS INCIDENCE AFTER WOUNDS OF NERVES

Authors	*Cases of Causalgia: Total*	*Sympathectomized*	*Total Number of Wounds Involving Nerves*	*Percentage of Incidence*	*Result of Sympathectomy: Excellent*	*Fair*	*Failure*
Doupe, Cullen, and Chance (1944)	7	5	—	—	100%	—	—
Mayfield and Devine (1945)	15	12	737	2.0%	100%	—	—
Speigel and Milowsky (1945)	9	7	275	3.3%	100%	—	—
Allbritten and Maltby (1946)	67	30	—	—	93%	—	7%
Rasmussen and Freedman (1946)	100	40	—	—	62.5%	10%	27.5%*
Ulmer and Mayfield (1946)	75	70	1477	5.0%	95.7%	—	—
Kirklin, Chenowith, and Murphey (1947)	52	18	—	—	69%	29%	2%
Shumacker (1948A)	—	257	—	—	76.3%	21%	2.7%
Slessor (1948)	28	17	670	1.2%	91%	16%	—
White, Heroy, and Goodman (1948)	14	11	400	3.3%	100%	—	—

*The discrepancy in the larger number of poor results reported by Rasmussen and Freedman is probably explained by their terminology. Their cases classified with the group of failures were reported as having "some persistent pain postoperatively."

approximately 60 per cent following wounds in the upper extremity and 40 per cent in the lower (Shumacker, 1948A). These references and the proportional incidence of causalgia are given in Table XIV. White's personal experience, published with Heroy and Goodman (1948), comprised 14 typical cases of classical causalgia in some 400 nerve injuries among the sailors and marines treated in the U. S. Naval Hospitals at Chelsea and St. Albans. The full-fledged condition is much less frequently seen in civilian practice, but an excellent account has been given by de Takats (1945).

Many aspects of the causalgic syndrome suggest that it is a form of psychoneurosis, and this diagnosis has often and most unfairly been applied to these victims. The fact that the whole pseudoneurotic picture so often clears immediately following suitable intervention, when the sufferer has lost his dread of pain, no longer requires sedatives, and can resume normal activities, indicates that the personality disturbance is a result rather than the cause of an unendurable condition. Psychological studies made after successful treatment (Mayfield and Devine, 1945; Speigel and Milowsky, 1945; de Takats, 1945) have not brought to light any predisposing psychogenic factors.

In the past, when no effective treatment was known, causalgia was a frequent cause of drug addiction and often led either to deterioration into chronic invalidism or to self-destruction. The former hopeless lot of these unfortunate individuals is best shown in John Mitchell's (1895) late description of some of his father's patients, written 30 years after the termination of the Civil War. Many of these had continued to suffer over long periods. As Shumacker concluded in his recent review, once the condition has reached the chronic stage there have been few reports of spontaneous remissions, even in patients followed over many months.

In numerous past descriptions of causalgia the authors have included with the classical syndrome of Weir Mitchell all varieties of burning pain which follow lesions of nerves. This unfortunate tendency is illustrated by the recent article of Macfarlane (1949) in which the pain of cauda equina lesions, arachnoiditis, injuries of the supraorbital nerve, and operative scars are all included as conditions giving rise to causalgia. Such indiscriminate classification has resulted in hopeless confusion and frequent failures of surgical therapy. The syndrome often referred to as "minor causalgia" should be limited to painful conditions which follow injuries to peripheral nerves and produce burning pain of lesser severity than the classical major causalgia described by Weir Mitchell. As Echlin *et al.* (1949) have pointed out, the condition differs only in severity from the classical syndrome. When the burning pain is influenced by environmental factors and can be relieved by sympathetic procaine block it should respond well to sympathectomy. Sympathectomy can be counted on to relieve only the true

whole hand at 2-8 volt thresholds. In two others, whose clinical complaint was post-traumatic pain in the upper limb, one had dull burning pain from shoulder to hand upon stimulus to either T2 or T3 ganglia. This persisted although it required a higher voltage to produce it after section of the rami communicantes to each of the two ganglia. In the second patient the T1 ganglion was stimulated at a reoperation for recurrence of pain after sympathetic regeneration following a T2-T3 ganglionectomy. Although 3 volts applied to the stellate ganglion caused slight pupillary dilatation and 5 volts produced a more pronounced response, pain, which reproduced the clinical complaint, was evoked in the medial part of the left arm and upper forearm only by 10-15 volts. This response at these voltages was obtained



Fig. 106. Post-traumatic dystrophy.

(*upper*). Characteristic attitude of patient, seen in Fay G. (Patient 38, Table XVIII).

(*middle and lower*). Trophic changes in this patient's right hand and fingernails.

causalgias with burning pain, glossy skin, trophic and vasomotor alterations, and exacerbations of symptoms concomitant with an increase in sympathetic activity. With the atypical variants this is not necessarily the case. Great care must therefore be taken in the selection of patients for operation to exclude by psychiatric tests and diagnostic paravertebral block with procaine those individuals in whom sympathectomy has no chance of success.

d. **Sympathetic dystrophies.**—Following trauma to the extremities and their articulations certain individuals develop an unusual train of symptoms which are related to a sympathetic reflex initiated by the trauma. When this is interrupted by chemical block or operation the response is often dramatic. These conditions are best classified under the general heading of "sympathetic dystrophies" and have been well described in recent articles by Holden (1948) and by Shumacker and Abramson (1949). They comprise painful post-traumatic osteoporosis (Sudeck's atrophy) and a miscellaneous group of painful post-traumatic and postinfectious states accompanied by vasospasm, cyanosis, excessive sweating, and trophic changes of the painful extremity. Holden rightly insists that the term "causalgia" should be reserved for "the burning painful syndrome that follows trauma to a major nerve in the extremity" and that "sympathetic dystrophy" be applied to other conditions which follow less specific trauma, infection, arthritis, etc. It is Holden's impression, and also our own, that sympathetic dystrophy occurs more frequently in maladjusted persons, whereas causalgia occurs chiefly in healthy young men who have shown little tendency to anxiety or hypochondriasis prior to their injuries. Holden also agrees with us that the sympathetic fibres to the extremities take no part in afferent pain conduction. He gives cogent reasons from his experiments, conducted in the Western Reserve laboratories, to controvert the claims of Kuntz with Farnsworth (1931) and Saccomanno (1942), Threadgill (1947), and Freeman, Shumacker, and Radigan (1950) that pain is conducted over sympathetic fibres in these conditions. The earlier animal experiments of Moore and Moore (1933) and Moore and Singleton (1933) and observations on conscious patients in the course of direct stimulation of the sympathetic trunks made by Walker and Nulsen (1948) have given no convincing evidence that painful impulses from the arm or leg are transmitted over other channels than the somatic nerves.

Our own patients in whom the T1, T2, or T3 ganglia have been stimulated have usually referred their ensuing pain to the chest or back, but in one of these (patient Eva S., in whom the operation was for treatment of hypertension) there was pain in the arm above the elbow upon application of 2 volts to either T1 or T2 ganglia. And in patient Ethel L. with Raynaud's syndrome stimulus of each of the two rami communicantes from the stellate ganglion to the first thoracic nerve caused prickling pain referred to the

brought out by the reports of Leriche and Fontaine (1935), Fontaine and Herrmann (1933), and by Gurd (1936), Miller and de Takats (1942), and Evans (1946) in this country. It is obvious that many of the trophic sequelae are due to prolonged disuse secondary to the associated pain. For a more complete review of the bibliography and specific case reports the reader should refer to Shumacker and Abramson's recent paper cited above.



Hyperaemia with increase in oscillometric measurements is seen in the early stage, accompanied by rapid onset of local oedema, muscular atrophy, and pain on the least movement of the affected joints (Fig. 106). The x-ray soon shows a mottled decalcification of the carpal or tarsal bones. In the more advanced stage there is general decalcification with loss of normal trabeculation (Fig. 107). The injured hand or foot becomes oedematous, cyanotic, clammy, and cold. The other extremities are often involved in the

five times. We must point out that in these last two patients the pain may have arisen from transmission of efferent sympathetic impulses across the known sites of nerve injury at the periphery to somatic afferent fibres. The high voltages required in the second case also lend support to the notion that normal pain fibres were not being activated in the stellate ganglion However, the responses of our patients Eva S. and Ethel L., as well as recent observations recorded by Echlin (1949) and Ellonen (1946) and discussed



Fig 107. Post-traumatic dystrophy: Degree of decalcification disclosed by x-ray of right hand, *above; on opposite page* arm and shoulder of Fay G. (Patient 38, Table XVIII).

below, force us to concede that there may be rare exceptions to the statement that pain fibres from the arm and leg do not enter the sympathetic trunk.

In post-traumatic dystrophy proper, first described by Sudeck in 1900, there is reflex atrophy with spotty calcification of bone following torsion or other, often minor, injuries in the region of a joint (most often the wrist or ankle). The predisposing factor of abnormal vasomotor and sudomotor activity and the therapeutic effectiveness of sympathectomy have been

Henderson and Smyth (1948) found that there is nearly always some awareness of the ghost of the missing extremity in the early period after a major amputation. Fortunately this phantom sensation is not generally associated with pain, and it usually fades away with the use of an artificial arm or leg. For a thorough analysis of the peculiar features of the phantom phenomenon the reader is referred to Browder and Gallagher's account (1946), to Henderson and Smyth's article based on observations of British prisoners captured at Dunkirk, and to Bornstein's (1949) description of his observations in another German prison camp.

In 6 per cent of amputees according to Pool (1946), but in only 2 per cent of those studied psychiatrically by Ewalt, Randall, and Morris (1947), the phantom fails to disappear, or may return months or years afterwards in an intensely painful form. Browder and Gallagher found that 79 out of 93 amputees admitted intermittent recurrence of phantom limb over periods of years. In 17 of these there was a painful sensation which eventually burned itself out, while in 10 others it became a cause of enduring complaint. The cause of this late exacerbation is usually additional trauma, which may be either organic or psychic. This took place as long as 18 years after leg amputation in one of our cases, following a fall with severe bruising of the stump.

The etiological factors underlying the phantom phenomenon are still not definitely known. Unlike the causalgic states, the circulation and degree of sweating in the stump are rarely abnormal, and the phantom is not evoked by local stimulation or sudden psychic disturbances. Irritation within a neuroma of centrally conducting axones which supplied the missing part prior to its amputation was formerly believed to be the primary source of this peculiar sensation. A consideration of all the factors concerned, however, indicates that this conclusion is not tenable. Evidence for this statement has been reviewed by K. E. Livingston (1945), who cites the following points: (1) End-bulb neuromas do not develop quickly enough to account for the early phases of the phantom limb, which may be present immediately after amputation. (2) Stimulation of a stump neuroma never produces the phantom sensation, but rather the usual tingling over the autonomous area of the peripheral nerve. (3) The typical phantom never represents irritation in the distribution of any single peripheral nerve: viz , there is no such thing as an "ulnar" or "peroneal" phantom. (4) Re-amputation rarely alters the phantom pattern.

Another point against the neuroma's being the focus of the phantom impulses, and one which Livingston fails to mention, is the fact that the uncomfortable position of the missing extremity so often duplicates the situation which existed prior to amputation. A final argument against local stimuli from the level of amputation being the source of the phenomenon,

abnormal vasomotor and sudomotor response. Pain and consequent immobility produce a vicious circle. To prevent irreversible damage to the joint, diagnosis must be made without delay and early therapy directed at breaking up the abnormal vasomotor reflexes and painful immobility of the extremity.

e. The shoulder-hand syndrome.—Evidence has recently been presented by Steinbrocker in a preliminary report (1947) and with Spitzer and Friedman (1948) for classifying nontraumatic vasomotor changes associated with pain, osteoporosis, and muscular and joint changes in the upper extremities as a reflex sympathetic dystrophy secondary to coronary disease. Although we have seen no instances of this association of sufficient severity to require surgical intervention, it is evident from the reports cited above and their numerous references to others that visceral reflex stimulation can account for cases in which the condition has developed without any history of trauma. Bayles *et al.* (1950) reported 17 cases in six of which characteristic changes in the arm and hand followed myocardial infarction. A similar syndrome developed in eight others following visceral symptoms of obscure origin, acromial bursitis, arthritis, and hemiplegia from embolism. In three, onset was spontaneous without any apparent predisposing cause whatever. Symptoms following coronary occlusion usually developed within four months to a year. Both Steinbrocker and Bayles were struck by the fact that a nodular thickening of the palmar aponeurosis similar to Dupuytren's contraction may occur following coronary thrombosis.

Without early diagnosis and prompt institution of proper treatment, trophic changes in the skin, subcutaneous tissues, joints, and bones rapidly developed. In the cases reported by Bayles and his colleagues, those seen in the early stage of reflex dystrophy responded to stellate block with immediate and complete relief from the pain and a gradual subsidence of paraesthesia and oedema in the subsequent two or three weeks. In patients with manifest trophic changes treatment by sympathetic block or even sympathectomy is not generally effective. This differs from our observations in post-traumatic dystrophy, where sympathetic denervation of the arm was often followed by relief of pain and at least some improvement in the trophic changes if the patient began to use the long immobilized extremity again.

f. Phantom limb.—The awareness of a phantom limb is a common phenomenon after amputation and has even been reported after amputation of the penis or testicles (see p. 593). Recognition of the syndrome dates back to an early description by Ambroise Paré in 1551. Mitchell (1871) gave a vivid description of his series of 90 cases and gave the syndrome its appropriate name. On careful questioning of amputees Leriche (1949) and

time of amputation. It is as if the postural model had become frozen when normal stimulation ceased." *One thing is certain: Once this pattern has become fixed after prolonged physical and emotional disturbance, no interruption of the pain tracts can abolish it.* The situation is similar to the tinnitus complained of by patients with Menière's disease. This is usually cured by early section of the auditory nerve, but when it has been present for a long time it may persist, even though the attacks of explosive dizziness are successfully relieved. Riddoch has given a most convincing argument for believing that the phantom sensation is a projection arising from the postcentral sensory association areas in the cerebral cortex. According to him:*

> "Stimulation by the processes of healing of the proximal ends of the divided nerves evokes sensations which are projected and interpreted as if the limb were still present. As has been said, they are never quite normal. These paraesthesiae, through simultaneous excitation of the schema underlying tactile localization and shape, are projected and animate the surface or outline model of the absent part. Similarly, irritation of the fibres concerned with postural sensibility gives rise to impulses which help to keep alive the postural model, so that the phantom is correctly placed and moves with the stump. These sensations, in the absence of pain, are, however, weak, so that, as a rule, only the peripheral segments, the hand or foot, which are most richly endowed with sensory end-organs and fibres, are represented in the phantom. Retention of the phantom is in part due to the abnormal qualities of the tactile and other sensations, in spite of their relative weakness and the antagonistic evidence from visual and other senses. During the stabilizing process of healing of the divided nerves, sensory impulses diminish, and sensations become correspondingly fainter, with the dual result that the phantom is increasingly less obvious in outline and projection of it is defective. In consequence, it gradually approaches the stump, into which it finally disappears and fades away. A new shape of the body is now accepted. In other words, there is no longer a conflict in evidence from the patient's senses. If, however, the phantom is painful, which is usually the result of grossly abnormal conditions in the stump, the phantom may persist indefinitely and retain its original position Further, the hand and fingers are not only much more obtrusive and clearly defined, but more of the amputated part is represented by it. Voluntary movement is restricted or impossible because of aggravation of pain."

If this concept is correct, the development of a central projection would be expected to take time to become established in the sensory cortex, a point which has been mentioned by Riddoch and emphasized by C. P. Symonds (personal communication, 1944). Furthermore, congenital ab-

---

*Riddoch, G.: Phantom limbs and body shape. *Brain*, London, 1941, *64*:197-222.

which cannot be lightly dismissed, is the development of a phantom limb after amputation in paraplegic patients with loss of all sensation in the lumbosacral segments. This has been reported by Li and Elvidge (1951) in a man with a crushing injury of his spinal cord and complete transverse myelitis at the midthoracic level. Eight days after this injury it was necessary to amputate his left leg at the knee because of a badly infected compound fracture of both bones in the lower leg. Four days later he became aware of his missing leg, which was extended at the knee and flexed at the ankle. There was a sensation of pressure pain in the phantom foot and shin. Bilateral lumbar sympathetic blocks did not alter these sensory phenomena in any way. Cook and Druckemiller (1952) have also described two individuals with missile wounds of the cord at the seventh and eleventh thoracic spinal segments. After amputation of a leg in each of them the characteristic postural phenomena soon became manifest, although pain does not appear to have been a serious complaint.

All of these features point to the fact that the phantom sensation is integrated at higher levels in the central nervous system. At first this may be situated at the reflex spinal level, as suggested by W. K. Livingston (1943). The fact that phantom pain can often be relieved by spinothalamic tractotomy proves that "a portion of its mechanism," at least, must be situated within the territory of the primary or secondary sensory neurones. Its persistence after apparently adequate cordotomy, which is occasionally the case, suggests that more centrally situated nervous pathways in such individuals can autonomously sustain this abnormal sensation.

At times the evolution of a painful phantom has all the appearance of being a purely psychic manifestation. This is illustrated by an unusual case report of Mayfield (personal communication, 1945). The patient, a tank soldier who had had his arm blown off above the elbow, had a perfectly comfortable upper arm stump until he applied for return to active duty. When this request was refused, he wanted to strike out with his amputated arm and clench his missing fist. He then became aware for the first time of his phantom hand, which remained clenched and painful. Although several neuromas were resected from the amputation stump, the phantom sensation was not relieved. However, as soon as he accepted the fact that he could not return to duty and asked for retirement, with the understanding that he could go overseas as a Red Cross Field Director, his phantom pain faded away. The amelioration of the phantom syndrome that can at times be achieved by effective psychiatric adjustment of the patient and his problems is discussed in Chapter IV (p. 110).

Evidence that this type of pain is often a central projection from the postcentral cortex has been summarized by Riddoch (1941), who pointed out that "the prevailing posture of the phantom is that of the part at the

when pain of this type is allowed to become chronic the cerebral cortex may become involved in its projection, so that no peripheral operation can relieve it; in addition, the patient usually develops an addiction to morphine and his morale deteriorates. Even in the less severe cases painful dysaesthesia prevents active and passive movement of injured joints and soft tissue and thereby leads to contractures, osteoporosis, and a great variety of trophic disturbances. Watchful waiting, in the hope that the pain will disappear spontaneously, is therefore not advisable for more than a very limited period. For these reasons we are forced to formulate a program to be undertaken when all conservative orthopaedic, physiotherapeutic, and neuropsychiatric measures have been tried and have failed.

Before recourse to surgery it is always essential to bear in mind that any ill-advised operation is likely to make the patient worse. The following pitiful case illustrates many of the difficulties in the treatment of post-traumatic pain.* A French soldier of World War I received a penetrating wound of the hand, which led to chronic suppuration, fibrosis, and pain. In the following 10 years he had undergone a long series of operations including amputation above the wrist, resection of painful neuromas, and subsequently progressive amputations up the arm, which ended with a painful shoulder stump and an intensely disagreeable phantom of the original wounded hand. Periarterial sympathectomy of the subclavian artery and section of the posterior roots of the brachial plexus failed to put an end to his suffering, which was finally terminated in 1927 through suicide. At that time little was known about what to do and, equally important, what not to do about a case of this sort. We are learning slowly, and many points are illustrated by this tragic story. In the first place, it is vitally important to avoid ineffective procedures. McKeever (1946) has observed that the pain in an amputation stump is usually increased by any operative procedure such as simple revision of flaps, in which the nerve stumps are not even exposed. Progress has been made since World War I through the realization that certain procedures are useless and should no longer be considered. These include:

Repeated resections of neuromas.

Neurectomies or interruption of nerve trunks at higher levels: W. K. Livingston (1943) has recorded a resection of the brachial plexus in a painful upper arm phantom without benefit, and we have had a similar experience; numerous other case reports since the time of Mitchell, Morehouse, and Keen (1864) are on record which attest its futility. Another variation of this procedure is the transection of a painful nerve trunk with immediate

*This patient was seen by one of us while working in Professor Leriche's clinic in Strasbourg in 1927.

sence of a limb never gives rise to awareness of a phantom, as the infant is born without a cortical schema of body shape and therefore never develops a sensory representation of the missing limb in its brain. A recent psychiatric evaluation of the phantom syndrome with interesting observations on the integration of centripetal impulses and the peculiarities of referred sensation has recently been published by Cronholm (1951). He brings out the fact that the phantom sensations with higher or medium intensity are much more common in patients with proximal than with distal amputations, and that the phenomenon is far more likely to occur in a patient who suffered pain in the extremity for some time before its amputation.

A final point which requires consideration is the relationship between the common varieties of pain following injuries of peripheral nerves. Some writers believe that pain from a neuroma, causalgia, and the phantom limb phenomenon are merely different clinical manifestations of the same underlying disorder. Mayfield and Devine (1945) believe that this similarity is remote and that causalgia is a separate clinical entity. Evidence now at hand also makes it possible to segregate the locally irritable end-bulb neuroma and the phantom limb as separate and distinct entities. While resection of neuromas, when they are constantly subjected to muscle traction, lack of soft tissue protection, and pressure from a prosthesis, will usually eliminate local tenderness, provided their reformation can be prevented, their removal in no way affects the pain of causalgia or a phantom limb. These last conditions are dissimilar, at least in the way they respond to emotional stimuli and react to the abolition of the efferent hypothalamic discharge following sympathectomy. The response of causalgia is nearly always favourable, while a painful phantom cannot often be influenced by this procedure. Barnes Woodhall (personal communication) has been fortunate enough to observe the response in a patient who suffered from both conditions simultaneously. After sympathetic denervation of the upper extremity, the burning hyperpathia of the forearm above the level of amputation, which had been so distressing after any exposure to cold or emotional stimuli, disappeared but the disagreeable cramp-like positions of the phantom hand remained.

B. TREATMENT

Despite our lack of a fundamental understanding of postamputation neuralgia, causalgia, and the painful phantom disturbances, several facts stand out clearly and require emphasis. Pain, considered by Hilton (1891) and by Mackenzie (1924) as a protective mechanism, may become a destructive force, dangerous to the victim's morale. As pointed out above,

by procaine block of the vasoconstrictor nerves or by fever therapy. In this connection, it is of interest to record the observation made by Mayfield and Devine (1945) at the Percy Jones General Hospital that soldiers with malaria are often relieved of pain from nerve injuries during bouts of fever.

Intrathecal injection of alcohol: This procedure, proposed by Dogliotti (1931), has been advocated for the relief of painful amputation stumps in the lower extremity. On the Neurosurgical Service at the Massachusetts General Hospital it has been successful only once out of seven trials. Furthermore, it carries a greater risk of paralyzing the bladder than section of the pain tracts. For any patient who has chronic pain and is even a fair surgical risk, it is preferable to transect the anterolateral quadrant of the spinal cord. We have two patients who had been treated elsewhere for severe neuralgia following thigh amputation by intrathecal injection with alcohol. Their pain was not relieved and both suffered from urinary retention afterwards—one for a year. Both have now been relieved for several years following anterolateral cordotomy and without any urinary complications (Table XIX, pts. 40 and 41).

Posterior rhizotomy: Extensive sectioning of the posterior roots of the brachial plexus is a serious and mutilating procedure. The widespread and complete loss of sensation which follows is annoying to the patient and incapacitating if he has a useful stump. For this reason, and even more because the anaesthetic stump usually continues to be painful, this procedure should never be undertaken. One of our patients with a painful amputation stump at the shoulder continued to suffer after division of all the posterior spinal roots from the third cervical down through the second thoracic, with section of anterior roots from C5 to T1 in addition. Here is a brief summary of this instructive case:

Julius S., old MGH#302623, aged 58, had fallen off a wagon seven years previously and suffered a compound fracture of his right upper arm. A high guillotine amputation followed by disarticulation at the shoulder had been performed on account of gas gangrene. Pain developed three months later, with twitching sensations in the phantom arm and contraction spasms of his shoulder muscles. On account of this he had been driven to submit to ten previous operations at other clinics: revision of stump, resections of neuromata, and neurectomy of brachial plexus. As neither local procaine nor paravertebral procaine injection gave him any relief. posterior root section was performed by Dr. R. H. Smithwick on 6/2/31 from the third cervical root through the second thoracic. The anterior roots of the plexus proper were cut as well. The latter effectively stopped the local muscular twitching in his stump, but he continued to suffer from his former pain in the neck and shoulder throughout the remaining three years of his life.

suture to prevent neuroma formation. Leriche (1949) described its use but reported no striking results.

Reamputation for the relief of pain: Reamputation must never be considered, as emphasized by Leriche (1949) and Riddoch (1941), *since the pain nearly always recurs in the new stump. There is only one exception to this rule:* When the stump is badly constructed and a liability on mechanical grounds, a reconstruction may be in order. Such a revision must be done at an early date, however, if it is to have any chance of relieving pain. This procedure failed after each of two amputations in Patient 3 in Table XV. Similarly, amputation cannot be counted on to relieve pain when *a partially injured nerve in continuity or one in which there has been* faulty regeneration after suture develops the phenomenon of over-response. This is illustrated by the following case history, where the original pain was reproduced by the postamputation phantom.

Charles L., MGH U-576989, 58 yrs., was referred to us from New York by Dr. G. K. Oxholm. Two years previously he had suffered a severe contusion of the ulnar nerve at the elbow. There had been an early transplantation of the nerve out of its epicondylar groove and a secondary neurolysis for pain ten months later. Removal of the second and third thoracic sympathetic ganglia had also been carried out without benefit. He suffered from burning hyperpathia along the medial forearm and the sensory area of the ulnar nerve. In August, 1947, one of us resected the scarred trunks of the ulnar and medial antebrachial cutaneous nerves and performed a technically satisfactory suture. The pain continued unimproved. When the patient asked us to recommend amputation we wrote his company doctor stating that this procedure might well lead to a reproduction of his complaints in a phantom arm. Despite this advice the lower arm was amputated. For the first six months all went well. Then his stump was bumped into by a fellow-worker and he is now reported to be tortured by his original pain in the phantom extremity.

Periarterial sympathectomy: Successful results in minor forms of causalgia and amputation stump pain after this operation have been recorded by Leriche (1949) and Homans (1940). Leriche, however, states that periarterial stripping should not be considered when the neuralgia is severe. Yet this unphysiological procedure is constantly mentioned in treatises on pain after nerve injury, such as Groff and Houtz's (1945) monograph, though without the statistical backing of successful case reports. It is the authors' personal feeling that the operation is nonspecific and that its effects are due to the transitory increase in peripheral circulation (or reduction of vasomotor tone) that accompanies the increased elimination of heat following any injury to the tissues. Similar effects can be produced more simply

Boldrey's (1943) suggestion of drawing the nerve end through a drill hole in a neighbouring bone (see Fig. 45, p. 169) at first appeared to be a hopeful method of preventing the re-formation of a neuroma. At the U. S. Naval Hospitals at Chelsea and St. Albans we treated digital nerves in this fashion in four patients without impressive results (Table XV, Pts. 1, 2, 4, 5). Another technique, which was developed by Spurling and employed by Woodhall at the Walter Reed General Hospital and by White and Hamlin (1945) at the U. S. Naval Hospital, Chelsea, is to cover the end of a nerve from which a neuroma has been removed with a snugly fitting cap of thin sheet tantalum. A description of this method has also been given by Coburn (1945). Details of the procedure are given on p. 170. This gave partial relief of the local symptoms in Patient 3, but only temporary benefit in Patient 6. Both Woodhall and White have had occasion subsequently to remove a few of these metallic caps, and have been impressed by the absence of neuroma formation. Nevertheless, we are not under any illusion that this is an answer to the problem.

Edds (1945) suggested painting the end of the nerve with 10 per cent solution of methyl methacrylate in acetone. In animal experiments it was found that the acetone caused complete chemical fixation of the stump, which is also imprisoned in an impervious plastic cap. Neuroma formation was never observed and the nerves tapered gradually to their blind ends. Theoretically, this method of encasing the end of the nerve in a nonirritant plexiglass (Lucite) cap should be a simple and most practical solution of the neuroma problem in small nerves, but it failed completely in Patient 12 (Table XV). Another more recent suggestion by W. V. Cone (personal communication, 1950) is to draw a short length of snug-fitting polyethylene tubing over the end of the nerve and fuse its open end together by crushing in the heated jaws of a haemostat. As tubing made of this material for electrical insulation is not irritant to tissue and can be bought commercially, it appears to be the simplest method of capping a nerve stump. We do not as yet have any proof of its effectiveness.

In the case of neuromas in continuity, when the patient is really incapacitated by the painful over-response which may follow faulty sensory regeneration, nothing has been accomplished by neurolysis. Theoretically, resection of the scarred portion of nerve and a technically perfect end-to-end anastomosis should correct the situation, if there is more perfect sensory return. This procedure is unquestionably worth a trial in case of pure sensory nerves like the saphenous, one of the antebrachial cutaneous trunks, or a digital nerve. With the latter the defect can be filled with an autograft, if direct suture is not possible. Bunnell (1944) has shown how well regeneration can take place after grafting these smaller nerves. With an important mixed nerve, however, like the median, the surgeon must weigh

Riddoch (1941) also emphasized the futility of posterior rhizotomy in these cases and stated that he had seen the pain continue after the anterior as well as the posterior roots of the brachial plexus had been cut.

Treatment of intensely painful "over-response" in cases of ulnar nerve injury by limited section of the eighth cervical and first thoracic posterior roots has recently been advocated by Herz and Yahr (1950). Resection of these two lowest roots of the brachial plexus does not lead to crippling loss of sensation in the hand, and it may possibly be an effective procedure in some cases of over-response after partial regeneration of the ulnar nerve. It is not, however, suitable in the more common cases when the median nerve is involved, because of the disabling anaesthesia and loss of position sense in the hand which occurs when the more important upper sensory roots of the brachial plexus are sacrificed. In the single case reported by Herz and Yahr the result was most gratifying, but the patient had only been observed for three months after operation. We have had a second equally gratifying result, now followed for 15 months. In another case in this identical situation our former associate, Dr. Bertram Selverstone, obtained equally effective relief of painful cutaneous hypersensitivity in the ulnar area for a number of months, but a year later this man has had a recurrence of such severe dysaesthesia that he is requesting high cervical cordotomy. Nothing can better illustrate the importance of waiting at least a year before drawing any conclusion about the results of operations performed for relief of pain, a rule which we have attempted to live up to throughout this book.

With the realization that the procedures mentioned above are so often ineffective and dangerous, what is left for the surgeon to do when he is confronted with these serious problems? There are three simple procedures that are often helpful and involve little chance of making matters worse:

1. Single Resection of a Painful Neuroma

A single resection of a sensitive neuroma is distinctly worth trying, provided the dysaesthesia is localized and can be relieved by infiltration of procaine. Formerly these neuromas often re-formed and pain recurred within a few weeks (Leriche, 1949; Bailey and Moersch, 1941). Injection of the freshly cut end of the nerve with alcohol does little to delay the reappearance of the neuroma, but injection of 20 per cent formalin or a 1 per cent aqueous solution of gentian violet is more effective (Guttmann and Medawar, 1942). This seems to have been effective in three service patients, although follow-up observations limited to a few months (Table XV, Pts. 5, 7, 8) are not satisfactory proof. This procedure was, however, ineffective in Patient 12.

6. Francis O. VAP USNH St Albans	30	Traumatic amputation below knee with excruciating tenderness over end of peroneal nerve. Also occasional shooting pain into missing lower leg.	9/45	Excision neuromata superficial and deep branches common peroneal nerve. Two ends of nerve covered with tantalum cap.	Relief of local tenderness lasted 3 mos., then partial recurrence with superimposed diffuse neuralgia of stump.
7 Otis W USNH St Albans	32	Traumatic amputation through 2nd and 3rd metacarpal heads with local pain and dysaesthesia in scar.	11/45	Resection 3 large neuromata and injection nerve ends with 20 per cent formalin.	Pain free at 2 mos.
8. Earl F. S 1/c USN USNH St. Albans		Traumatic amputation ring finger through proximal phalanx. Stump so tender he was unable to grip anything.	1/46	Excision digital neuromata and injection nerve ends with 20 per cent formalin.	Pain free at 2 mos., able to use hand freely.
9. Fred J. MGH U-357214 (Dr. H. Marble)	71	Partial severance of median nerve at wrist. Stinging, burning dysaesthesia of palm and first 3 fingers.	3/15	Resection of scar and suture of median nerve.	Gradual disappearance of pain with progressive recovery of sensation over 4-year period of follow-up.
10. Robert H. MGH U-617730	24	Severed median nerve in proximal palm. Intense dysaesthesia of palm and base of first 3 fingers proximal to total anaesthesia of fingertips.	5/48	Late exploration, resection of end-bulb neuroma, and suture.	No improvement, but at 12 mos. still no signs of regeneration.
11 Cora B MGH U-623508BM	39	Postoperative injury of digital nerves at base of middle finger following fasciotomy. Extreme dysaesthesia of contiguous surfaces of middle and ring fingers.	7/18	Excision of digital nerve caught in scar with end-to-end suture.	No reduction of hypersensitivity despite good regeneration of sensation at 6 mos.
12. Joseph B MGH U-666614BM	68	Traumatic amputation of 3 fingers with local and phantom pain. Forearm amputation 3 yrs. later without alteration of pain.	6/19	Resection of sensitive median neuroma. End injected with formalin and painted with methyl methacrylate (Lucite cap).	Pain relieved for 4 mos., but then recurred as bad as ever. He has since been relieved by Ritchie Russell method of percussing the median neuroma.

Table XV

RELIEF OF LOCAL AMPUTATION NEURALGIA BY EXCISION OF NEUROMA MODIFIED BY PROCEDURES TO PREVENT REFORMATION

(8 of these patients were operated upon during World War II in the U. S. Naval Hospitals at Chelsea and St. Albans.)

Patient	Age	Condition	Date	Surgical Procedure	Result
1. Edward G. S 3/c USN USNH Chelsea	26	Traumatic amputation 2nd and 3rd fingers. Exquisite pain in stumps and deep ache in hand and forearm Cold, cyanotic, sweaty hand.	1/44	1) Digital nerves of 3rd finger freed from terminal neuromata and drawn through drill holes in proximal phalanx.	Relief of local dysaesthesia of middle finger, but no effect on deep ascending pain. Index finger still hypersensitive at 2 mos.
				2) See Table XVI.	
2. Roy B. S 1/c USN USNH Chelsea	26	Severe scarring of sides of index finger by crushing accident. Local dysaesthesia both sides of finger.	3/44	1) Paravertebral sympathetic ganglion block.	No effect on pain.
				2) Amputation finger-tip Lateral digital nerve drawn through drill hole in proximal phalanx.	Loss of dysaesthesia over lateral side of finger at 7½ mos. with persistence of pain on medial side.
3. Philip C. Sgt. USMC USNH Chelsea	28	Traumatic amputation tip 5th finger, with repeated amputations to metacarpal level for local tenderness of stump and deep ache in hand and arm.	8/44	1) Resection of neuroma from medial digital nerve, enclosure of stump in tantalum cap.	Relief of dysaesthesia only, with no effect on underlying neuralgia at 4 mos.
				2), 3) See Table XVI.	
4. Henry J. CM 3/c USN USNH Chelsea	21	Traumatic amputation distal phalanges 4th and 5th fingers. Local tenderness and deep ascending neuralgia.	10/44	1) Plastic revision poorly constructed 5th finger stump, excision of neuromata, and drawing of digital nerves through drill hole in middle phalanx.	Relief of local dysaesthesia only but persistent ascending neuralgia and continued dysaesthesia in stump of 4th finger.
				2) See Table XVI.	
5. Cleveland J. SC 2/c USN USNH St. Albans	36	Traumatic amputation tip of middle finger with severe dysaesthesia.	7/45	1) Resection neuromata, burial digital nerve ends in drill hole through bone of 2nd phalanx.	Little improvement.
			8/45	2) Revision and shortening of painful stump. Digital nerves injected with 20 per cent formalin.	A month later all severe pain gone though slight tenderness persisted.

6. Francis O. VAP USNH St. Albans	30	Traumatic amputation below knee with excruciating tenderness over end of peroneal nerve Also occasional shooting pain into missing lower leg.	9/45	Excision neuromata superficial and deep branches common peroneal nerve. Two ends of nerve covered with tantalum cap.	Relief of local tenderness lasted 3 mos, then partial recurrence with superimposed diffuse neuralgia of stump.
7. Otis W. USNH St. Albans	32	Traumatic amputation through 2nd and 3rd metacarpal heads with local pain and dysaesthesia in scar	11/45	Resection 3 large neuromata and injection nerve ends with 20 per cent formalin.	Pain free at 2 mos.
8. Earl F. S 1/c USN USNH St. Albans		Traumatic amputation ring finger through proximal phalanx. Stump so tender he was unable to grip anything.	1/46	Excision digital neuromata and injection nerve ends with 20 per cent formalin.	Pain free at 2 mos., able to use hand freely.
9. Fred J. MGH U-357214 (Dr. H. Marble)	71	Partial severance of median nerve at wrist. Stinging, burning dysaesthesia of palm and first 3 fingers.	3/45	Resection of scar and suture of median nerve.	Gradual disappearance of pain with progressive recovery of sensation over 4-year period of follow-up.
10. Robert H. MGH U-617730	24	Severed median nerve in proximal palm. Intense dysaesthesia of palm and base of first 3 fingers proximal to total anaesthesia of fingertips.	5/48	Late exploration, resection of end-bulb neuroma, and suture.	No improvement, but at 12 mos. still no signs of regeneration.
11 Cora B. MGH U-623508BM	39	Postoperative injury of digital nerves at base of middle finger following fasciotomy. Extreme dysaesthesia of contiguous surfaces of middle and ring fingers.	7/48	Excision of digital nerve caught in scar with end-to-end suture.	No reduction of hypersensitivity despite good regeneration of sensation at 6 mos.
12. Joseph B. MGH U-666644BM	68	Traumatic amputation of 3 fingers with local and phantom pain. Forearm amputation 3 yrs. later without alteration of pain.	6/49	Resection of sensitive median neuroma. End injected with formalin and painted with methyl methacrylate (Lucite cap).	Pain relieved for 4 mos., but then recurred as bad as ever. He has since been relieved by Ritchie Russell method of percussing the median neuroma.

Table XV

RELIEF OF LOCAL AMPUTATION NEURALGIA BY EXCISION OF NEUROMA MODIFIED BY PROCEDURES TO PREVENT REFORMATION

(8 of these patients were operated upon during World War II in the U. S. Naval Hospitals at Chelsea and St. Albans)

Patient	Age	Condition	Date	Surgical Procedure	Result
1. Edward G. S 3/c USN USNH Chelsea	26	Traumatic amputation 2nd and 3rd fingers. Exquisite pain in stumps and deep ache in hand and forearm. Cold, cyanotic, sweaty hand.	1/44	1) Digital nerves of 3rd finger freed from terminal neuromata and drawn through drill holes in proximal phalanx.	Relief of local dysaesthesia of middle finger, but no effect on deep ascending pain. Index finger still hypersensitive at 2 mos.
				2) See Table XVI.	
2. Roy B. S 1/c USN USNH Chelsea	26	Severe scarring of sides of index finger by crushing accident. Local dysaesthesia both sides of finger.	3/44	1) Paravertebral sympathetic ganglion block.	No effect on pain.
				2) Amputation finger-tip. Lateral digital nerve drawn through drill hole in proximal phalanx.	Loss of dysaesthesia over lateral side of finger at 7½ mos. with persistence of pain on medial side.
3. Philip C Sgt. USMC USNH Chelsea	28	Traumatic amputation tip 5th finger, with repeated amputations to metacarpal level for local tenderness of stump and deep ache in hand and arm.	8/44	1) Resection of neuroma from medial digital nerve, enclosure of stump in tantalum cap.	Relief of dysaesthesia only, with no effect on underlying neuralgia at 4 mos.
				2), 3) See Table XVI.	
4. Henry J. CM 3/c USN USNH Chelsea	21	Traumatic amputation distal phalanges 4th and 5th fingers. Local tenderness and deep ascending neuralgia.	10/44	1) Plastic revision poorly constructed 5th finger stump, excision of neuromata, and drawing of digital nerves through drill hole in middle phalanx.	Relief of local dysaesthesia only but persistent ascending neuralgia and continued dysaesthesia in stump of 4th finger.
				2) See Table XVI.	
5. Cleveland J. SC 2/c USN USNH St. Albans	36	Traumatic amputation tip of middle finger with severe dysaesthesia.	7/45	1) Resection neuromata, burial digital nerve ends in drill hole through bone of 2nd phalanx	Little improvement.
			8/45	2) Revision and shortening of painful stump. Digital nerves [illegible]	[illegible]

given temporary relief. He claims that the continued percussion produc progressive fibrosis of the nerve end with shrinkage of the neuroma. Painl neuromata in the arm have responded less well to percussion treatme than those in the leg, but in failures where the neuroma is deeply situat Russell has found it helpful to explore, crush the neuroma, and transpl it close beneath the skin for more efficient percussion. The most diffic cases to treat are those where the nerves have been cut far back in t stump. Some of these have been treated by percussion after a prelimin shortening of the stump, at which time the sensitive end-bulbs have be sutured under the skin. The neuroma should never be resected. If perc sion is too painful, the discomfort can be mitigated by preliminary appli tion of a tourniquet or by local injection of procaine.

One of us had the opportunity of visiting the Nuffield Department Surgery at Oxford in May, 1950, and was profoundly impressed by t results in the first 33 cases. Comments of several of the patients were interest. One who had been unable to sleep stated, "I really think t nerve is afraid of the mallet." Another said that "the phantom makes attempt to come back about once every three weeks, but it is too feeble trouble me in any way and I can usually knock it away in 10 minutes hammering."

Our own preliminary results with this method, which was tried as sc as Russell's first article appeared, were not very impressive, but this v probably due to inefficient application rather than to any inherent fa in the method. With the recent incentive of having seen the work in pr ress at Oxford and with a satisfactory electrically driven percussor, are making every effort to duplicate Russell's success and advise ev surgeon who has to deal with these cases to give this very simple a practical method a thorough trial. At the present time of writing th patients with traumatic amputations remain free of pain for periods up six hours after two daily periods of percussion. We have also had to failures in an ulnar and a posterior tibial neuroma, which were accessi to percussion and were given a thorough trial by the manual method.

3. Sympathectomy

In patients with vasomotor and emotional disturbances, which are commonly found in these painful states, much can be done by the elimi tion of the regional sympathetic outflow to the painful extremity. This c be accomplished either by repeated chemical blocking with procaine by sympathectomy. When pain is relieved during the period of sympathe block, but reappears as the drug is absorbed, there is a very good chai that surgical interruption of the regional sympathetic outflow will br about lasting relief. Occasionally a single sympathetic block, or its rep

the possibility of less perfect return of function in the intrinsic muscles of the hand in any instance where opponens function is not entirely lost. Although one would expect painful hypersensitivity to clear up if a suture is successful in establishing a sufficient degree of reinnervation of the cutaneous sensory endings (see page 361), regeneration has continued beyond the stage of unpleasant "over-response" in only one of the three attempts listed in Table XV. In this case (Pt. 9), in whom Dr. H. C. Marble sutured the median nerve at the wrist, the dysaesthesia of the palm and first three fingers disappeared at the time that he had a return of light touch and two-point discrimination to 2 cm. in the autonomous zone.

The methods reported above are simple and theoretically sound procedures. They deserve careful clinical trial, but nevertheless it must be borne clearly in mind that the period of follow-up in our war-time cases, was too short to permit any accurate assessment of their value. Furthermore, it must be admitted that we have witnessed failures after every variety of procedure used to prevent recurrence. We are therefore forced to admit a considerable degree of pessimism over relieving these conditions with certainty by any minor surgical procedure which has been proposed to date.

2. Mechanical Percussion of Neuromata

Ritchie Russell (1949), having observed a patient with sensitive digital amputation neuromata who was able to gain relief from pain by striking these areas vigorously against a solid object, has recommended repeated percussion as a simple and often effective method of treatment. In his preliminary paper a number of promising results were reported. A much more complete report was published by Russell and Spalding in 1950. The procedure consists of pounding directly over the sensitive neuroma. A round wooden applicator about 2 cm. in thickness is used with a crutch rubber at one end and a smooth, rounded metal cap at the other.* This end is held firmly against the skin over the neuroma and the rubber-covered end struck rapidly with a wooden mallet for periods of up to 20 minutes several times a day. The patient or one of his family can be taught to do this in the home. Percussion with a mechanical vibrator is proving even more satisfactory.** The duration and frequency of percussion can be reduced as soon as improvement has started. Russell has found that the procedure works best in cases in which local injection of procaine has

*The half-inch size "domes of silence," sold in hardware stores for capping the legs of chairs, serve this purpose very well.

**An excellent electrical instrument for this purpose is manufactured by Robert C McShurley of Glendale, California. This "Percussomotor" can be adjusted to control the frequency and force of percussion

given temporary relief. He claims that the continued percussion produces progressive fibrosis of the nerve end with shrinkage of the neuroma. Painful neuromata in the arm have responded less well to percussion treatment than those in the leg, but in failures where the neuroma is deeply situated Russell has found it helpful to explore, crush the neuroma, and transplant it close beneath the skin for more efficient percussion. The most difficult cases to treat are those where the nerves have been cut far back in the stump. Some of these have been treated by percussion after a preliminary shortening of the stump, at which time the sensitive end-bulbs have been sutured under the skin. The neuroma should never be resected. If percussion is too painful, the discomfort can be mitigated by preliminary application of a tourniquet or by local injection of procaine.

One of us had the opportunity of visiting the Nuffield Department of Surgery at Oxford in May, 1950, and was profoundly impressed by the results in the first 33 cases. Comments of several of the patients were of interest. One who had been unable to sleep stated, "I really think the nerve is afraid of the mallet." Another said that "the phantom makes an attempt to come back about once every three weeks, but it is too feeble to trouble me in any way and I can usually knock it away in 10 minutes of hammering."

Our own preliminary results with this method, which was tried as soon as Russell's first article appeared, were not very impressive, but this was probably due to inefficient application rather than to any inherent fault in the method. With the recent incentive of having seen the work in progress at Oxford and with a satisfactory electrically driven percussor, we are making every effort to duplicate Russell's success and advise every surgeon who has to deal with these cases to give this very simple and practical method a thorough trial. At the present time of writing three patients with traumatic amputations remain free of pain for periods up to six hours after two daily periods of percussion. We have also had total failures in an ulnar and a posterior tibial neuroma, which were accessible to percussion and were given a thorough trial by the manual method.

3. Sympathectomy

In patients with vasomotor and emotional disturbances, which are so commonly found in these painful states, much can be done by the elimination of the regional sympathetic outflow to the painful extremity. This can be accomplished either by repeated chemical blocking with procaine or by sympathectomy. When pain is relieved during the period of sympathetic block, but reappears as the drug is absorbed, there is a very good chance that surgical interruption of the regional sympathetic outflow will bring about lasting relief. Occasionally a single sympathetic block, or its repeti-

Table XVI

RELIEF OF DIFFUSE PAIN IN POST-TRAUMATIC NEUROMAS BY INTERRUPTION OF SYMPATHETIC FIBRES

(The Service patients were operated upon in the U. S. Naval Hospitals at Chelsea and St. Albans.)

Patient	*Age*	*Condition*	*Surgical Procedures*	*Result*
1. Edward G. S 3/c USN USNH Chelsea	26	Traumatic amputation 2nd and 3rd fingers Dysaesthesia in 3rd finger had been relieved by excision of neuroma, but without effect on neuralgia of hand and forearm.	1) Plastic procedures to stump. See Table XV. 2) 1/44. Procaine block T 1-T2. 3) 2/44: Upper thoracic preganglionic sympathectomy.	No effect on neuralgia. Temporary relief. Complete relief of ascending neuralgic pain. Pt. still complained of hypersensitive index finger but was able to return to limited duty.
3. Philip C. Sgt. USMC USNH Chelsea	28	Traumatic amputation tip of 5th finger with repeated amputations to metacarpal level for local dysaesthesia and deep ache in hand and arm. Cold, cyanotic hands.	1) Plastic procedures to stump. See Table XV. 2) 4/44: Procaine block of upper thoracic ganglia. 3) 9/44: Upper thoracic preganglionic sympathectomy.	No effect on neuralgia. Relief for 2 hrs. Nearly complete relief of deep aching pain in hand and arm at 3 mos., but little finger still somewhat painful.
4. Henry J. CM 3/c USN USNH Chelsea	21	Traumatic amputation of distal phalanges of 4th and 5th fingers with diffuse ascending neuralgia. Very cold, cyanotic, sweaty hands.	1) Plastic procedures to stump. See Table XV. 2) 11/44: Upper thoracic preganglionic sympathectomy.	No effect on neuralgia. Warm hand and arm free of former deep pain at discharge and when seen 6 yrs. later.
13. Roger P. MGH #302151	30	Traumatic amputation of index finger following crush by machine. Post-traumatic pain radiating to axilla. Cold, moist extremities.	1) 10/18/29: Procaine block upper thoracic ganglia. 2) 10/21/29: Revision of stump. 3) 2/7/30: Sympathetic ganglionectomy T 1-T2.	Relief for 2 hrs. No effect on pain. Complete relief for 20 yrs. to date.
14. Roland L. BM #879	29	Traumatic amputation tip of index finger in newspaper press followed by dull, aching pain radiating up arm, associated with vasomotor disturbances in both hands.	1) 7/30: Exploration and revision of finger stump. 2) 11/17/30: Procaine block of upper thoracic ganglia. 3) 11/21/30: Sympathetic ganglionectomy.	No benefit. Transitory relief. Effective relief, but inadequate follow-up.

15. James L. ABS RN USNH Chelsea	?	Traumatic metatarsal amputation with painful vasospasm. Deep ache in end of foot, which became much worse in cold weather and ascended to knee.	1) 6/21/43 Procaine block of lumbar ganglia 2) 6/27/43. Sympathectomy L2-L3	Temporary relief. Excellent result.
16. Henry C. S 2/c USN USNH St. Albans	23	Traumatic amputation of 3rd toe with severe pain in stump and bottom of foot. Aggravated by cold but not by psychic stimuli.	1) 10/8/45: Procaine block of lumbar ganglia. 2) 10/12/45: Sympathectomy L2-L3.	Temporary relief. Complete relief at 2 mos.
17. Ralph T. MGH U-382923	53	Traumatic midthigh amputation in 1918 with severe stump neuralgia 20 yrs. later.	1) 11/42: Procaine block of lumbar ganglia. 2) 11/45: Spinothalamic tractotomy, level at T3. 3) 11/47: Sympathectomy L1-L3.	Very transitory relief. Complete relief for 23 mos., then 50% recurrence of pain with fall in analgesia level to T 12. No relief. This operation done at patient's insistence with warning it would not be effective and that higher cordotomy should be performed instead.
18. Freeman M. MGH U-623508 Dr. B. Selverstone	54	Postoperative cicatrix of superficial radial and lateral antebrachial cutaneous nerves following resection of radial bursa with intense "over-response" in hypaesthetic area.	1) 5/48: Neurolysis with transplantation of nerves to healthy muscular bed. 2) 5/50: Paravertebral procaine block. 3) 6/50: Upper thoracic sympathectomy.	No improvement in 19 mos. Temporary relief. Complete relief at 1 yr.

tion once or several times, will have an equally good and lasting effect. We have had such fortunate experiences in several cases of post-traumatic dystrophy.

Experience with seven cases of peripheral amputation stump neuralgia is summarized in Table XVI. This method is most effective when the pain results from a lesion in the lower arm or leg with associated vasospasm, and particularly when the pain is increased by exposure to cold or emotional stimuli. In five of these cases excellent results were obtained, and there was definite improvement in the other two. Both of these (Patients 1 and 3) were relieved of the ascending neuralgia, although the amputated finger stumps remained somewhat hypersensitive. Patient 3 was also most grateful for the improved circulation in his hand. These successful results were obtained only in cases of amputation below the wrist or ankle.

We have seen no improvement after higher amputations. Patient 43 (Table XIX) obtained no amelioration of the burning pain in his amputated thigh following lumbar ganglionectomy. Patient 17 with similar complaints had been relieved by a previous cordotomy, but suffered a partial recurrence with a fall in the level of analgesia. He insisted on having a trial of lumbar ganglionectomy, although paravertebral procaine block failed to give even temporary respite. We told him that sympathectomy had no chance of relieving this type of high amputation pain but, since he insisted, compromised with the proviso that he let us stimulate his lumbar ganglia under local anaesthesia. The interesting results of this experiment have already been cited above (p. 88). Suffice it to state at this point that stimulation of the intact sympathetic chain produced only deep abdominal (visceral) pain and that its resection in no wise relieved his residual discomfort.

Patient 18, a man with the syndrome of intensely painful over-response, is of particular interest because of the effective relief obtained by sympathectomy. In the past this syndrome has been singularly resistant to neurosurgical measures short of cordotomy. In this case the exacerbation of the patient's symptoms on exposure to cold fortunately led Dr. Bertram Selverstone to make a diagnostic stellate injection. During the period of block his disagreeable tingling dysaesthesia cleared. All manifestations of oversensitivity have disappeared in the 12 months following sympathectomy.

The most consistent and dramatic results of sympathectomy have been in patients with typical Weir Mitchell causalgia. In this condition local neurolysis and freeing of the nerve from a surrounding cicatrix (as illustrated in Figure 101, Patient 24) or resection of a lateral neuroma are seldom successful (Mayfield and Devine, 1945, Speigel and Milowsky, 1945).*

*Mayfield (1951) in his recent monograph has also emphasized this point. He claims, however, that causalgic pain will cease if the neuroma in continuity is excised and an end-to-end suture performed.

Neurolysis or suture of the injured nerve to relieve pain is justifiable only when there is definite paralysis and when the causalgia is so mild that the surgeon can afford to wait for a period of months while the irritated nerve fibres regenerate. If the pain is really severe, it is far better judgment to perform the sympathectomy first (provided there has been a promising response to paravertebral procaine block) and to postpone any necessary local repair of the nerve trunk until afterwards. Patient 20 in Table XVII serves to illustrate this point. Multiple shell fragments, in passing through



Fig. 108. Causalgia.
Preoperative photograph of Patient 20, Table XVII, to illustrate wounds in arm and characteristic position in which patient kept it immobilized. Hand was usually protected by moist towel. Note moisture of palm and swelling of hand.
From White, Heroy, and Goodman: *Ann. Surg.*, 1948.
Courtesy, J. B Lippincott Co, Philadelphia.

the arm, had nicked the median and severed the ulnar nerve (Figs. 108 and 109). This patient had suffered from excruciating dysaesthesia and burning pain in his hand, which first developed several hours after he was wounded at Iwo Jima and had persisted uninterruptedly for four months. He could not tolerate the noise and minor excitements of the open ward, but lay by himself in a darkened room with his painful hand wrapped in a moist towel. There was immediate transitory relief of his severe causalgic pain on three occasions following procaine block, and complete relief observed for over a year following sympathectomy. Subsequently the nerves were explored widely with median neurolysis and transplantation of the ulnar nerve from the epicondylar groove to gain sufficient slack for end-to-end suture over the extensive gap.

Preganglionic* denervation of the upper extremity or resection of the lumbar sympathetic ganglia are both safe and nonmutilating procedures. These operations therefore deserve serious consideration with early testing by procaine block when incapacitating pain persists following a nerve wound or peripheral trauma, especially when this is accompanied by abnormal

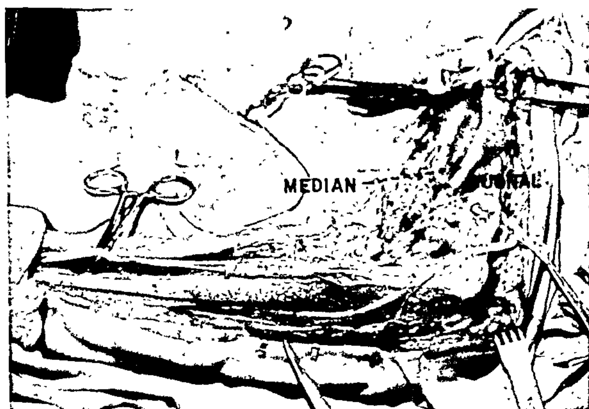


Fig. 109. Causalgia

Photograph of Patient 20, Table XVII, taken at secondary exploration preliminary to suture of severed ulnar nerve. Note wide gap in ulnar and lateral neuroma of median nerve. In lower forearm neither median nor ulnar nerve was injured. The median is shown elevated by the haemostat

From White, Heroy, and Goodman *Ann Surg.*, 1948. Courtesy, J. B. Lippincott Co., Philadelphia.

vasomotor and sudomotor manifestations, or is made worse by psychological factors. When pain disappears for the duration of the chemical sympathectomy the patient with the clinical picture of sympathetic dystrophy should be told frankly that complete relief cannot be guaranteed, but that there is high probability that sympathectomy will result in a satisfactory outcome and a certainty that the abnormal peripheral circulation and sweating

*The preganglionic type of denervation of the upper extremity has been a most satisfactory procedure for relief of the neuralgias described above. It does not produce a Horner's sign and there have been no recurrences secondary to nerve regeneration, which have been such a troublesome factor after this type of sympathectomy for Raynaud's disease.

will be rectified. In the case of the worse causalgias the outlook is even more promising.

The results in our 14 cases summarized in Table XVII were almost completely satisfactory, and the over-all experience after 257 sympathectomies recently collected by Shumacker (1948A) shows an excellent reponse in 196, good in an additional 54, and poor in only seven.

Relief of pain with improvement of function in the sympathetic dystrophies (Sudeck's atrophy) has been almost as impressive as in causalgia. All six cases in Table XVIII had complete relief of their pain after paravertebral procaine block. Three required no further treatment than one or more injections. Three others had only brief amelioration and required sympathectomy. Relief was then complete in two. In Patient 36 there has been a late recurrence of the previous pain in the wrist, but this is not severe enough to prevent work in a shoe factory, where she has continued to be employed for nearly a year and a half.

Examples of treatment by these two methods are given herewith:

Patient 33, Louis G., Old MGH #304623, 44 yrs. Following fracture of the carpal scaphoid five years before, this expressman had had constant trouble with his left wrist. The bones had become widely decalcified. Two years prior to admission the ununited fragments had been removed without benefit. This hand was distinctly cooler than his right and all movements were restricted by pain. There were also diffuse atrophy and tenderness. On diagnostic procaine block (2/14/30) the finger temperature rose from 74° to 94°; his pain and limitation of movement disappeared. At this time we were unaware of the fact that multiple injections alone might restore normal function. Upper thoracic sympathectomy would have been performed without further delay, had it not been for a fortunate complicating iodine dermatitis. He was discharged on this account and, remaining free of pain, returned to his work with the express company. He was able to carry on for five months and then re-entered the hospital when he began to require further help. After the second injection he was again relieved for a period of six months, and after a third injection was permanently cured.

Patient 35, Barbara F., MGH U-161712, 16 yrs. This girl, a patient of Dr. Edward Hamlin, complained of pain of spontaneous origin on movement of her left foot. The onset was insidious and for seven months the aching in her instep had radiated up to her knee and become so severe that she could barely walk. This foot was several degrees cooler and distinctly moister than her right, and extreme decalcification was seen in the x-ray of the lower leg as compared with the normal side. Paravertebral procaine block caused a striking rise in cutaneous temperature (13°F.) and she was able to walk freely for several hours without pain. Relief in this patient, however, was but transitory, so on 5/2/40 Dr. Hamlin resected the upper three lumbar sympathetic ganglia, with a thoroughly satisfactory result.

Preganglionic* denervation of the upper extremity or resection of the lumbar sympathetic ganglia are both safe and nonmutilating procedures. These operations therefore deserve serious consideration with early testing by procaine block when incapacitating pain persists following a nerve wound or peripheral trauma, especially when this is accompanied by abnormal

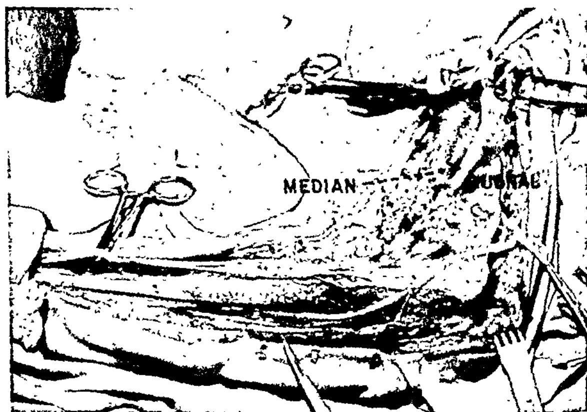


Fig. 109. Causalgia.

Photograph of Patient 20, Table XVII, taken at secondary exploration preliminary to suture of severed ulnar nerve Note wide gap in ulnar and lateral neuroma of median nerve In lower forearm neither median nor ulnar nerve was injured The median is shown elevated by the haemostat.

From White, Heroy, and Goodman: *Ann Surg.*, 1948 Courtesy, J. B. Lippincott Co., Philadelphia.

vasomotor and sudomotor manifestations, or is made worse by psychological factors. When pain disappears for the duration of the chemical sympathectomy the patient with the clinical picture of sympathetic dystrophy should be told frankly that complete relief cannot be guaranteed, but that there is high probability that sympathectomy will result in a satisfactory outcome and a certainty that the abnormal peripheral circulation and sweating

*The preganglionic type of denervation of the upper extremity has been a most satisfactory procedure for relief of the neuralgias described above. It does not produce a Horner's sign and there have been no recurrences secondary to nerve regeneration, which have been such a troublesome factor after this type of sympathectomy for Raynaud's disease.

will be rectified. In the case of the worse causalgias the outlook is even more promising.

The results in our 14 cases summarized in Table XVII were almost completely satisfactory, and the over-all experience after 257 sympathectomies recently collected by Shumacker (1948A) shows an excellent reponse in 196, good in an additional 54, and poor in only seven.

Relief of pain with improvement of function in the sympathetic dystrophies (Sudeck's atrophy) has been almost as impressive as in causalgia. All six cases in Table XVIII had complete relief of their pain after paravertebral procaine block. Three required no further treatment than one or more injections. Three others had only brief amelioration and required sympathectomy. Relief was then complete in two. In Patient 36 there has been a late recurrence of the previous pain in the wrist, but this is not severe enough to prevent work in a shoe factory, where she has continued to be employed for nearly a year and a half.

Examples of treatment by these two methods are given herewith:

Patient 33, Louis G., Old MGH #304623, 44 yrs. Following fracture of the carpal scaphoid five years before, this expressman had had constant trouble with his left wrist. The bones had become widely decalcified. Two years prior to admission the ununited fragments had been removed without benefit. This hand was distinctly cooler than his right and all movements were restricted by pain. There were also diffuse atrophy and tenderness. On diagnostic procaine block (2/14/30) the finger temperature rose from 74° to 94°; his pain and limitation of movement disappeared. At this time we were unaware of the fact that multiple injections alone might restore normal function. Upper thoracic sympathectomy would have been performed without further delay, had it not been for a fortunate complicating iodine dermatitis. He was discharged on this account and, remaining free of pain, returned to his work with the express company. He was able to carry on for five months and then re-entered the hospital when he began to require further help. After the second injection he was again relieved for a period of six months, and after a third injection was permanently cured.

Patient 35, Barbara F., MGH U-161712, 16 yrs. This girl, a patient of Dr. Edward Hamlin, complained of pain of spontaneous origin on movement of her left foot. The onset was insidious and for seven months the aching in her instep had radiated up to her knee and become so severe that she could barely walk. This foot was several degrees cooler and distinctly moister than her right, and extreme decalcification was seen in the x-ray of the lower leg as compared with the normal side. Paravertebral procaine block caused a striking rise in cutaneous temperature (13°F.) and she was able to walk freely for several hours without pain. Relief in this patient, however, was but transitory, so on 5/2/40 Dr. Hamlin resected the upper three lumbar sympathetic ganglia, with a thoroughly satisfactory result.

Table XVII

RELIEF OF CAUSALGIA BY PARAVERTEBRAL SYMPATHECTOMY

(These patients were operated upon during World War II in the U. S. Naval Hospital at St. Albans. Their complete case histories are given in the paper by White, Heroy, and Goodman, 1948)

Patient	Age	Wound	Paralysis	Distribution of Pain	Time of Onset After Wounding	Hyperpathia	Relation To: Cold	Relation To: Emotion	Operations in Addition to Sympathectomy	Result of Sympathectomy
19. Charles R. Pfc. USMC	19	Small shell fragments L. upper arm.	Median nerve (partial).	Entire hand.	Few hours.	+++	+++	+++	Early median neurolysis overseas without improvement.	Complete relief, playing strenuous games at 7 mos. Working at 7 yrs.
20. Frederick S. Pvt. USMC	19	Shell fragments upper arm and forearm (Fig. 108).	Median nerve (partial), ulnar nerve (complete).	Entire hand.	5 hrs.	+++	+++	+++	Subsequent median neurolysis and ulnar nerve suture.	All dysaesthesia cleared. Slight residual ache in finger-tips at 8 yrs.
21. John H. Maj. USMC	25	Upper humerus fractured by shell fragment. False aneurysm in axilla.	Median nerve (complete), ulnar nerve (partial).	Entire hand but most pronounced in ulnar area.	Immediate.	++	++	+++	Aneurysmorrhaphy. Median nerve sutured later.	Complete relief at 5 yrs.
22. Norman C Pfc. USMC	23	Machine gun bullet passed between two upper forearm bones.	Median and radial nerves (partial).	Entire hand.	Few hours.	++	++	0	Previous neurolysis and partial suture of median and radial nerves, with incomplete relief.	Complete relief at 8 yrs.
23. Charles M. Pfc. USMC	19	Rifle bullet through upper arm. Artery severed.	Median and ulnar nerves, complete at first, later partial spontaneous recovery.	Entire hand.	2 wks., after operation for aneurysm.	++	++	++	Ligation of brachial artery 2 wks. after wounding.	Complete relief, followed 8 yrs.

24. Nathan V. Pvt. USMC	27	Rifle bullet through upper forearm, fractured ulna.	Median nerve (partial).	Median distribution.	—	++	+	++	Neurolysis of median nerve without relief. (Fig. 103.)	Complete relief, followed 5 yrs.
25. Robert B. Cpl. USMC	23	Bullet wound brachial plexus, fractured clavicle, severed artery.	Median and ulnar nerves (partial), musculocutaneous and medial antebrachial cutaneous nerve (complete).	Entire hand.	1 wk.	+++	++	+++	None.	Hyperpathia of hand gone, but at times slight residual pain elbow and wrist at 3 yrs.
26. Alfred D. Pfc. USMC	22	Mortar wound median side of arm, axilla to midforearm.	Median nerve (partial), musculocutaneous (complete).	Median area of hand.	Day after wound.	+++	++	++	Block of brachial plexus without relief.	Complete relief, doing well at 8 yrs.
27. Howard W Pfc. USMC	31	Bullet wound below elbow.	Median nerve (partial).	Median area of hand.	Immediate.	++	++	++	Previous median neurolysis, without improvement.	Working with slightly sensitive hand at 3 yrs.
28. Harold O. Pfc. USMC	22	Shell fragment wound of internal condyle of elbow.	Ulnar nerve (partial).	Ulnar area of hand.	Immediate.	++	++	++	Previous ulnar neurolysis, without improvement.	Working with slightly sensitive hand at 8 yrs.
29. William M. Cpl. USMC	20	Phosphorus grenade fragments in lower leg.	Posterior tibial and common peroneal (partial), sural nerve (complete).	Entire foot and toes.	Immediate.	+++	++	++	None.	First sympathectomy incomplete, failed to relieve anterior third of foot. Satisfactory relief after completion sympathetic denervation and neurolysis. Followed 4 yrs.

TABLE XVII

RELIEF OF CAUSALGIA BY PARAVERTEBRAL SYMPATHECTOMY—Continued

Patient	*Age*	*Wound*	*Paralysis*	*Distribution of Pain*	*Time of Onset After Wounding*	*Hyperpathia*	*Relation To: Cold*	*Relation To: Emotion*	*Operations in Addition to Sympathectomy*	*Result of Sympathectomy*
30. John B. Gm 2/c USN	19	Razor slash across palm.	Median nerve (complete at first, then partial recovery).	Median area.	6 mos. after wounding with partial regeneration.	++	+	++	Immediate suture of median nerve.	Satisfactory relief over 7 yr. period of follow-up.
31. Donald M. Lt. (jg) USNR	29	Penetrating wound of lower thigh.	Posterior tibial and common peroneal nerves (partial).	Sole of foot, especially on medial side.	Immediate.	+++	++	+++	None.	Complete relief over 3 yr. period of follow-up.
32. John S. 1st Lt. USMC	24	Gunshot wound with intertrochanteric fracture femur.	Sciatic nerve (partial).	Entire foot and lower leg.	Uncertain. Leg in cast.	++	+	0	Removal plate on account of sepsis.	Two paravertebral lumbar procaine blocks gave prolonged but not quite sufficient relief. Excellent result 8 mos. after lumbar ganglionectomy.

Patient 26 had such severe paroxysms of pain in his hand on swallowing anything cold that he was able only to sip warm liquids. This most unusual complaint was relieved temporarily by procaine block and permanently after preganglionic sympathectomy.

Patient 30 complained of increase of pain on urination and defaecation, an uncommon feature, but one that has been previously recorded. This complication disappeared after sympathectomy, along with his other complaints.

TABLE XVIII

RELIEF OF PAIN IN POST-TRAUMATIC DYSTROPHIES BY PROCAINE BLOCK AND SYMPATHECTOMY

Patient	*Age*	*Condition*	*Sympathetic Nerve Procedures*	*Result*
33. Louis G. MGH U-304623	44	Fracture of carpal bone with chronic oedema, osteoporosis, and pain.	1) 2/30: Procaine block of upper thoracic ganglia. 2) 7/30: Re-injection. 3) 1/31: Final injection.	Returned to work as expressman free of pain. Pain gradually recurred, and was again relieved by injection. No further complaints, normal function of hand.
34. Case treated by Dr. H. H. Faxon		*Post-traumatic painful osteoporosis* secondary to carpal fracture.	*Single* paravertebral procaine injection of upper thoracic ganglia.	Pain free, returned to work, no further follow-up.
35. Barbara F. MGH U-161712 Dr E. Hamlin, Jr.	16	Spontaneous development of osteoporosis in L. foot with pain radiating to knee.	1) 5/21/40: Procaine block of lumbar ganglia. 2) 5/22/40: L. sympathetic ganglionectomy L1-L3.	Relief for several hours. Immediate relief of pain with full weight bearing, which was maintained for follow-up period of 2 yrs.
36. Evelyn M MGH U-655847	37	Traumatic fracture carpal bone, incapacitated by painful osteoporosis. *Fragments resected without benefit* 4 yrs. previously.	1) Paravertebral procaine block. 2) 10/49: Preganglionic sympathectomy.	Early complete relief of pain. Partial recurrence after 6 mos., but she continues to work in shoe factory at 17 mos.
37. Mary L MGH U-318061BM	28	Longstanding rheumatoid arthritis with pain and osteoporosis developing 1 yr. ago after burn of fingers.	1-3) Paravertebral procaine block. 4) 11/49: Preganglionic sympathectomy (Dr. R. M. P. Donaghy).	Complete but temporary relief. Excellent result at 1 mo.
38. Fay G. MGH U-686381BM	74	Shoulder contused in fall 2 yrs. previously with gradual onset of osteoporosis of arm and crippling pain.	12/49. Stellate procaine block by anterior approach (Dr. D. H. Todd).	Complete relief at 10 mos.

TABLE XVII

RELIEF OF CAUSALGIA BY PARAVERTEBRAL SYMPATHECTOMY—Continued

Patient	*Age*	*Wound*	*Paralysis*	*Distribution of Pain*	*Time of Onset After Wounding*	*Hyperpathia*	*Relation To: Cold*	*Emotion*	*Operations in Addition to Sympathectomy*	*Result of Sympathectomy*
30. John B. Gm 2/c USN	19	Razor slash across palm.	Median nerve (complete at first, then partial recovery).	Median area.	6 mos. after wounding with partial regeneration.	++	+	++	Immediate suture of median nerve.	Satisfactory relief over 7 yr. period of follow-up.
31. Donald M. Lt. (jg) USNR	29	Penetrating wound of lower thigh.	Posterior tibial and common peroneal nerves (partial).	Sole of foot, especially on medial side.	Immediate	+++	++	+++	None.	Complete relief over 3 yr. period of follow-up.
32. John S. 1st Lt. USMC	24	Gunshot wound with intertrochanteric fracture femur.	Sciatic nerve (partial).	Entire foot and lower leg.	Uncertain. Leg in cast.	++	+	0	Removal plate on account of sepsis.	Two paravertebral lumbar procaine blocks gave prolonged but not quite sufficient relief. Excellent result 8 mos. after lumbar ganglionectomy.

Patient 26 had such severe paroxysms of pain in his hand on swallowing anything cold that he was able only to sip warm liquids. This most unusual complaint was relieved temporarily by procaine block and permanently after preganglionic sympathectomy.

Patient 30 complained of increase of pain on urination and defaecation, an uncommon feature, but one that has been previously recorded. This complication disappeared after sympathectomy, along with his other complaints.

When these relatively simple and innocuous operations cannot be used, the surgical attack must be shifted to the central nervous system. Before recourse to more radical intervention on the spinal cord or brain can be considered, all aspects of the problem should be reviewed with a competent neuropsychiatrist. Lidz and Payne (1945) have cited the case of a young soldier who shot off the middle finger of his right hand while cleaning his rifle. Typical severe causalgia developed seven weeks later when he heard that his unit believed that the wound was self-inflicted to avoid service at the front. The pain persisted until the situation was explained to him and he was given encouragement under the influence of Sodium Pentothal. When he decided to prove himself in combat and regain the respect of his friends, the entire situation cleared up.* Another equally striking case is cited above (p. 110). In this highly sensitive individual a painful phantom after thigh amputation had led to total incapacity and narcotic addiction. Under Dr. Stanley Cobb's care in this hospital psychotherapy has resulted in effective relief of his symptoms and return to his former responsible position. Successful results of this sort are, unfortunately, extremely rare.

Operations on the spinal cord and brain may precipitate unfortunate complications and, if they fail, will add another psychic trauma with further reduction of the patient's morale. Recourse to such radical surgery should, therefore, be undertaken only in desperate cases in which pain is so severe that the situation can be controlled in no other way. Then it should be undertaken without further delay before the sufferer becomes addicted or a hopeless psychoneurotic.

4. Section of Spinothalamic Tract

When the phenomenon of painful over-response following incomplete regeneration of a peripheral nerve is present to such a degree that the patient is totally incapacitated or forced to resort to narcotic medication, we do not hesitate to recommend anterolateral cordotomy. This, as mentioned above, is the only procedure that carries a reasonably certain chance of success. While easy to carry out when the injured nerve is in the lower extremity, we have been reluctant to recommend it for interruption of pain in the median area, as experience has shown that it is difficult to produce permanent analgesia to the upper level of the brachial plexus. In a recent case of this sort we were driven in desperation to carry out an anterolateral

*It would be of great theoretical interest to know whether this dramatic result was brought about by lessening the tonic discharge of sympathetic impulse to the extremities, which is so greatly increased at times of emotional disturbance. Cobb (1943) has recorded instances of the development of Raynaud's phenomenon following periods of intense psychic strain, so this possibility would fit in well with the role of the sympathetic discharge in the production of causalgic pain hypothecated by Doupe, Cullen, and Chance (1944).

Shumacker and Abramson (1949), who have had an unusually wide experience with painful post-traumatic dystrophies in 142 soldiers, claim that some individuals can overcome this condition by simple perseverance with forced active exercise. The majority, however, will require relief from pain before they are willing to cooperate. These authors, like ourselves, have found that this desired result can frequently be achieved by single or repeated sympathetic blocks, which often relieved vasospasm and dysaesthesia long enough to permit the patient to start physiotherapy. Early activity and strenuous use of the injured extremity are the primary requisites for successful treatment. When the syndrome is of long duration paravertebral block is rarely sufficient. Sympathectomy is often effective, although the likelihood of a completely successful outcome is less in the advanced case with motor weakness, extensive atrophy, and the mental attitude of the chronic invalid.

How often the painful phantom phenomenon can be relieved by sympathetic block or ganglionectomy is still not definitely established. De Takats (1945) has recommended its trial and W. K. Livingston (1938), Ellonen (1946), Echlin (1949),* and Scott and Wycis (1949) have reported some favourable results, but in the authors' experience neither local nor regional block has proved successful. The most numerous enthusiastic reports have come from Ellonen in Finland. In view of this the article of his compatriot Kallio (1950) is of more than passing interest. In the latter's experience, after more prolonged observation of a larger series of cases, it was found that sympathetic surgery, either injection or resection of the regional ganglia, had no lasting effect in 39 and in one made the pain worse. In 29 cases the immediate results were good, but after one to four years only six patients reported that they were cured and one said that his pain was less severe. Echols and Colclough (1947) have recorded a painful postamputation phantom that developed following a preliminary lumbar sympathectomy in a man with gangrene from thromboangiitis obliterans, and we have recently had an identical experience on the peripheral vascular service of the Massachusetts General Hospital (John M., MGH U-745167). During the war Dr. Barnes Woodhall showed one of us on a visit to the Walter Reed Army Hospital a young lieutenant who had suffered simultaneously from burning causalgic pain in his lower forearm amputation stump and from a disagreeable phantom of the missing hand, contracted in the position in which he last saw it prior to its amputation. A month after an upper thoracic preganglionic sympathectomy the patient stated that he was relieved of his causalgic pain, but that the painful phantom of his hand remained unchanged.

---

*See page 89 for a summary of Echlin's case in which pain in the phantom part was reproduced by stimulation of the lumbar sympathetic chain at operation

When these relatively simple and innocuous operations cannot be used, the surgical attack must be shifted to the central nervous system. Before recourse to more radical intervention on the spinal cord or brain can be considered, all aspects of the problem should be reviewed with a competent neuropsychiatrist. Lidz and Payne (1945) have cited the case of a young soldier who shot off the middle finger of his right hand while cleaning his rifle. Typical severe causalgia developed seven weeks later when he heard that his unit believed that the wound was self-inflicted to avoid service at the front. The pain persisted until the situation was explained to him and he was given encouragement under the influence of Sodium Pentothal. When he decided to prove himself in combat and regain the respect of his friends, the entire situation cleared up.* Another equally striking case is cited above (p. 110). In this highly sensitive individual a painful phantom after thigh amputation had led to total incapacity and narcotic addiction. Under Dr. Stanley Cobb's care in this hospital psychotherapy has resulted in effective relief of his symptoms and return to his former responsible position. Successful results of this sort are, unfortunately, extremely rare.

Operations on the spinal cord and brain may precipitate unfortunate complications and, if they fail, will add another psychic trauma with further reduction of the patient's morale. Recourse to such radical surgery should, therefore, be undertaken only in desperate cases in which pain is so severe that the situation can be controlled in no other way. Then it should be undertaken without further delay before the sufferer becomes addicted or a hopeless psychoneurotic.

4. Section of Spinothalamic Tract

When the phenomenon of painful over-response following incomplete regeneration of a peripheral nerve is present to such a degree that the patient is totally incapacitated or forced to resort to narcotic medication, we do not hesitate to recommend anterolateral cordotomy. This, as mentioned above, is the only procedure that carries a reasonably certain chance of success. While easy to carry out when the injured nerve is in the lower extremity, we have been reluctant to recommend it for interruption of pain in the median area, as experience has shown that it is difficult to produce permanent analgesia to the upper level of the brachial plexus. In a recent case of this sort we were driven in desperation to carry out an anterolateral

*It would be of great theoretical interest to know whether this dramatic result was brought about by lessening the tonic discharge of sympathetic impulse to the extremities, which is so greatly increased at times of emotional disturbance. Cobb (1943) has recorded instances of the development of Raynaud's phenomenon following periods of intense psychic strain, so this possibility would fit in well with the role of the sympathetic discharge in the production of causalgic pain hypothecated by Doupe, Cullen, and Chance (1944).

Shumacker and Abramson (1949), who have had an unusually wide experience with painful post-traumatic dystrophies in 142 soldiers, claim that some individuals can overcome this condition by simple perseverance with forced active exercise. The majority, however, will require relief from pain before they are willing to cooperate. These authors, like ourselves, have found that this desired result can frequently be achieved by single or repeated sympathetic blocks, which often relieved vasospasm and dysaesthesia long enough to permit the patient to start physiotherapy. Early activity and strenuous use of the injured extremity are the primary requisites for successful treatment. When the syndrome is of long duration paravertebral block is rarely sufficient. Sympathectomy is often effective, although the likelihood of a completely successful outcome is less in the advanced case with motor weakness, extensive atrophy, and the mental attitude of the chronic invalid.

How often the painful phantom phenomenon can be relieved by sympathetic block or ganglionectomy is still not definitely established. De Takats (1945) has recommended its trial and W. K. Livingston (1938), Ellonen (1946), Echlin (1949),* and Scott and Wycis (1949) have reported some favourable results, but in the authors' experience neither local nor regional block has proved successful. The most numerous enthusiastic reports have come from Ellonen in Finland. In view of this the article of his compatriot Kallio (1950) is of more than passing interest. In the latter's experience, after more prolonged observation of a larger series of cases, it was found that sympathetic surgery, either injection or resection of the regional ganglia, had no lasting effect in 39 and in one made the pain worse. In 29 cases the immediate results were good, but after one to four years only six patients reported that they were cured and one said that his pain was less severe. Echols and Colclough (1947) have recorded a painful postamputation phantom that developed following a preliminary lumbar sympathectomy in a man with gangrene from thromboangiitis obliterans, and we have recently had an identical experience on the peripheral vascular service of the Massachusetts General Hospital (John M., MGH U-745167). During the war Dr. Barnes Woodhall showed one of us on a visit to the Walter Reed Army Hospital a young lieutenant who had suffered simultaneously from burning causalgic pain in his lower forearm amputation stump and from a disagreeable phantom of the missing hand, contracted in the position in which he last saw it prior to its amputation. A month after an upper thoracic preganglionic sympathectomy the patient stated that he was relieved of his causalgic pain, but that the painful phantom of his hand remained unchanged.

---

*See page 89 for a summary of Echlin's case in which pain in the phantom part was reproduced by stimulation of the lumbar sympathetic chain at operation

When these relatively simple and innocuous operations cannot be used, the surgical attack must be shifted to the central nervous system. Before recourse to more radical intervention on the spinal cord or brain can be considered, all aspects of the problem should be reviewed with a competent neuropsychiatrist. Lidz and Payne (1945) have cited the case of a young soldier who shot off the middle finger of his right hand while cleaning his rifle. Typical severe causalgia developed seven weeks later when he heard that his unit believed that the wound was self-inflicted to avoid service at the front. The pain persisted until the situation was explained to him and he was given encouragement under the influence of Sodium Pentothal. When he decided to prove himself in combat and regain the respect of his friends, the entire situation cleared up.* Another equally striking case is cited above (p. 110). In this highly sensitive individual a painful phantom after thigh amputation had led to total incapacity and narcotic addiction. Under Dr. Stanley Cobb's care in this hospital psychotherapy has resulted in effective relief of his symptoms and return to his former responsible position. Successful results of this sort are, unfortunately, extremely rare.

Operations on the spinal cord and brain may precipitate unfortunate complications and, if they fail, will add another psychic trauma with further reduction of the patient's morale. Recourse to such radical surgery should, therefore, be undertaken only in desperate cases in which pain is so severe that the situation can be controlled in no other way. Then it should be undertaken without further delay before the sufferer becomes addicted or a hopeless psychoneurotic.

4. Section of Spinothalamic Tract

When the phenomenon of painful over-response following incomplete regeneration of a peripheral nerve is present to such a degree that the patient is totally incapacitated or forced to resort to narcotic medication, we do not hesitate to recommend anterolateral cordotomy. This, as mentioned above, is the only procedure that carries a reasonably certain chance of success. While easy to carry out when the injured nerve is in the lower extremity, we have been reluctant to recommend it for interruption of pain in the median area, as experience has shown that it is difficult to produce permanent analgesia to the upper level of the brachial plexus. In a recent case of this sort we were driven in desperation to carry out an anterolateral

*It would be of great theoretical interest to know whether this dramatic result was brought about by *lessening* the tonic discharge of sympathetic impulse to the extremities, which is so greatly increased at times of emotional disturbance. Cobb (1943) has recorded instances of the development of Raynaud's phenomenon following periods of intense psychic strain, so this possibility would fit in well with the role of the sympathetic discharge in the production of causalgic pain hypothecated by Doupe, Cullen, and Chance (1944).

Table XIX

RELIEF OF LOCAL PAIN AFTER AMPUTATION BY ANTEROLATERAL CORDOTOMY

Patient	*Age*	*Condition*	*Date*	*Level of Operation*	*Side*	*Sensory Level*	*Result*
39. William D. MGH #277838 Dr. J. S. Hodgson	41	L. Gritti-Stokes amputation for thromboangiitis obliterans. Deep aching pain in stump of 3½ yrs. duration.	3/31	T2*	R.	T9	Relieved on L. side to death at 3½ yrs.
		After first cordotomy and a R. Gritti-Stokes amputation developed pain in R. stump, also painful gangrene of fingers	10/34	C3	L.	C7	Died 7 days after L. cervical cordotomy of bronchopneumonia.
40. Nelllie T. MGH U-107222	64	Burning pain in stump since thigh amputation for osteomyelitis 8 yrs. before. At other hospitals had had unsuccessful sciatic neurectomy, multiple excisions of neuromas, and intrathecal alcohol injection; latter caused bladder disturbance for 1 yr.	2/38	T2*	L.	T8	Complete relief at 3 mos.
41. Emma H MGH U-8600	41	Mid-thigh amputation following septic abortion. Local pain in stump of 2 yrs. duration. Previous intrathecal alcohol injections had paralyzed bladder without mitigating pain.	5/39	T2*	R.	T 10	Complete relief for 10 yrs., but complained of radicular pain at level of laminectomy. This disappeared after 3 yrs. and pt. has led normal life since cordotomy.
42. James B. MGH U-222390	57	Burning pain developing in stump 30 yrs. after thigh amputation.	3/43	T2*	R.	T 12	Relief for 4½ mos., then recurrence following transurethral prostatectomy. Problem complicated by senile psychosis.
17. Ralph T. MGH U-382923 Dr. W. J. Mixter	53	Traumatic thigh amputation above knee 26 yrs. before. Past 7 yrs. crises of intense bursting pain in stump, especially at night. Stump well formed, non-tender, pt. walked freely with prosthesis. Temporary relief following spinal anaesthesia to T6.	11/45	T3*	R.	T 12	See also Table XVI. Complete relief 2½ mos. Analgesic level later fell to T12 with partial recurrence of pain. At 3 yrs. graded himself 50 per cent improved. After 8 yrs. only low-grade hypalgesia and is little improved.

43. Daniel M. MGH U-526300	34	Traumatic low thigh amputation 3 yrs. before. Tenderness and burning pain in stump, driving pt. to drink. Unable to use prosthesis. Previous excision sciatic neuroma and sympathetic ganglionectomy without benefit. Temporary relief following full spinal anaesthesia.	1/10	T3*	R.	T9-L 1	Pt. walked out of hospital on prosthesis, free of stump neuralgia at 9 mos. At 1 yrs. pain free at rest but unable to tolerate pressure of prosthesis in groin, where analgesia was incomplete.
			3/50	T2*	R.	T9	Again free of pressure pain and able to use prosthesis at 1 yr.
44. John D. MGH U-530657	55	Low thigh amputation 14 yrs. before for malignant tumour of tibia, followed in last 4 yrs. by deep aching, burning pain, became alcoholic on this account. No local tenderness.	5/10	T3*	L.	T 11	At 3 yrs. local physician reports he is pain free, sensory level just below umbilicus maintained.

No troublesome motor weakness or bladder disturbance in any.
*Sensory level tested at operation.

cordotomy at the second cervical level. This woman had partially injured her median nerve at the wrist, having only minimal opponens weakness. Dysaesthesia was so severe that she had been unable to grasp with the thumb and index finger for two years. Neurolysis and thoracic sympathectomy had been performed without benefit by surgeons at other hospitals. Our cordotomy has only partially relieved her because of a fall in the initial level of analgesia.

From our experience with postamputation neuralgia, there is good evidence that pain and tenderness which are located within the stump itself can usually be relieved by cordotomy. Seven cases are summarized in Table XIX, five of which obtained lasting satisfactory relief. Patient 17 had a late mild recurrence of his former pain. Failure to secure lasting complete relief in this patient and the late complete return of symptoms in Patient 42 were due to sinking of the level of analgesia. The death in Patient 39 occurred in a poor risk case with advanced thromboangiitis obliterans. Three and a half years after an excellent result from his first cordotomy he had developed pain in the opposite hand, as well as in the stump of his second thigh amputation. He died after a high cervical cordotomy of bronchopneumonia.

In the case of severe phantom manifestations the decision as to whether relief can be obtained by spinothalamic tractotomy becomes more difficult. From their extensive experience at the Mayo Clinic Bailey and Moersch (1941) concluded that no form of surgical intervention is effective. Riddoch (1941), however, was not so pessimistic and stated that when "pain in the phantom is successfully abolished by lateral chordotomy or early removal of abnormalities in the stump, the phantom may behave as if it had been painless from the first." Nevertheless, Riddoch agreed that no relief could be expected when the pain has become stamped indelibly on the cerebral cortex.

We have divided the anterolateral quadrant in 10 patients complaining of painful leg phantoms (Table XX). It will be seen that the severe crushing or cramping pains in the phantom foot have been relieved in seven instances, but one case (Patient 53) had a return of some local pain in his stump when the level of analgesia dropped. This was relieved by a second more radical cordotomy. Another patient (Case 50) developed annoying paraesthesiae, although he admitted complete relief of his painful phantom. Patient 49 was free of pain for eight months after each of two cordotomies, but he then complained of recurrent pain in his phantom on the appearance of islands of hypalgesia. Disagreeable sensations of heat and pressure then made it impossible for him to wear his artificial leg. In Patient 57, with bilateral thigh amputations and severe phantom pain in both legs, we were unable to obtain total analgesia on either side. As a result this man con-

TABLE XX

RELIEF OF PHANTOM LIMB PAIN AFTER AMPUTATION BY SECTION OF SPINOTHALAMIC TRACT

Patient	Age	Condition	Date	Level of Operation	Sensory Level	Result
45. Charles W. MGH U-17250	70	Pain in phantom foot 18 yrs., following thigh amputation. Two previous unsuccessful resections of neuromas.	7/41	T2*		At 2½ yrs. pt. remained comfortable, although at times had slight throbbing sensation in phantom little toe. Spasmodic jumping of stump had ceased.
46. Arthur N. MGH U-303667	61	Crushing pain in phantom ankle following hip disarticulation for sarcoma 2 mos. previously	12/41	T2*	T7	In good condition and pain free at 27 mos., but had awareness of phantom with some sense of stiffness in foot and big toe.
47. Homer A. MGH U-391227	51	Pinching, burning pain in phantom foot 7 mos. after hip disarticulation.	2/43	T2*	T9	Complete loss of phantom sensations at 8 mos.; still complained of spasmodic jerking of stump with sense of muscle cramp and mild radiculitis at level of laminectomy incision.
48. Percy J. Queen Elizabeth Hospital, Birmingham, England	44	Pain in phantom hand following traumatic amputation of arm just below shoulder. Previous operations: Drainage of infected stump, 3 revisions of scar, and supraclavicular division of brachial plexus with alcohol injection of central ends.	5/43	Medulla 2 mm. below obex*	C3	Persistent paraesthesias in face ipsilateral to section in medulla. Freedom from all pain in phantom and amputation stump for 3 yrs., then progressive discomfort until at 5 yrs. phantom pain was again severe
49. Mahlon D. MGH U-501059BM	40	Pain in phantom thigh and in amputation stump despite cordotomy 7/41. Taking morphine sulfate 16 mg. 4 to 6 a day.	9/45	T2*	T5	Pain free phantom and stump 8 mos. Gradual return of discomfort in stump so that by 10/47 often had to remove prosthesis because of pressure and heat sensations.
		With return of pain complete analgesia had been replaced by areas in stump where repetitive pinpricks were disagreeable.	5/49	C7*	T5	No complication to secondary section. Relief of phantom pain again complete, but recurred at 9 mos.
50. Albert D. MGH U-131237	73	Pain in phantom leg and foot, also in amputation stump below knee and in thigh 17 yrs. Temporary relief with differential spinal block.	12/45	T3*	T5	All phantom sensation and pain relieved but burning pain in stump worse than before operation. Pt. furious because he could put pin through stump and not realize he had done so.

Table XX

RELIEF OF PHANTOM LIMB PAIN AFTER AMPUTATION BY SECTION OF SPINOTHALAMIC TRACT—Continued

Patient	*Age*	*Condition*	*Date*	*Level of Operation*	*Sensory Level*	*Result*
51. James D. MGH U-83267	66	Mid-thigh amputation for diabetic gangrene in 1944 followed by pain referred to formerly sensitive big toe and cramps in sole of foot.	9/46	T3*	Hypalgesia T7, analgesia T10	Hypertrophied prostate required transurethral resection. He then voided well. Free of all pain as well as of phantom sensations at 1½ yrs.
52. Frank I. MGH U-552763PH	51	Shooting pain in stump and burning in phantom foot for 18 mos. following hip disarticulation. Chondrosarcoma recurrent in acetabulum.	11/46	T2*	T7	Failure. Considerable improvement following bilateral frontal leucotomy until death 3 mos. later from pulmonary metastases.
53. Nelson B. MGH U-369540	42	Bilateral stump neuralgia following amputation at mid-thigh for *thromboangiitis obliterans. Previous* lumbar sympathectomies. On R., phantom foot projected from stump with toes curled in preamputation position. Demerol q. 3 *h. for months without adequate* relief.	5/48	T2*	T8	Complete relief at 1 mo. Level of complete analgesia then fell with return of *neuralgia in stump*, but continued relief of phantom pain at 13 mos.
			5/49	T3*	T10	Residual pain in stump disappeared.
54. Robert S. Worcester Hospital Dr. J. T. B. Carmody and W.H.S.	53	Traumatic forearm amputation with pain. Cortical sensory gyrectomy (see p. 413) with early recurrence.	6/48	C2*	C3 to mid-thorax	Despite apparently complete analgesia, painful phantom fingers project from stump at 9 mos.
55. Marguerite M. MGH U-637766BM	48	Scapulohumeral amputation for neurosarcoma 17 mos. previously, followed by phantom of arm in cramped position with elbow and *wrist in extreme flexion. Anterior* and posterior rhizotomy, cortical sensory gyrectomy, and shock treatment at other hospitals.	10/48	C1	C3	Painful cramping sensation disappeared for 3 mos. At 6 mos. complete return of phantom concurrent with drop in level of analgesia. On rapid pin-prick anywhere in lower body disagreeable sensation is referred to stump.
56. Josephine B MGH U-6676	37	Old poliomyelitis with recurrent infection necessitated Gritti-Stokes amputation in 1945. 29 hospital admissions. Entered for pain in stump and phantom sensations, which she feared no one would believe.	10/48	T3*	Hypalgesia T5, analgesia T8	Free of all pain in stump and disagreeable phantom sensations at 2½ yrs.

57. Wylie S. MGH U-440170	60	Bilateral traumatic mid-thigh amputations 5¾ yrs. previously. Immediate appearance of intensely disagreeable phantoms of feet twisted under ends of stumps.	3/49	T2 (L)*	T8	Phantom sensation returned in full force on R. after 1 mo., concurrent with appearance of islands of hypalgesia in stump.
			10/49	T1, T3 (Bilat.)*		Partial relief on L., but return of painful phantom on R. Analgesia incomplete in both stumps.
			1/50	C4 (L)*		High-grade hypalgesia to T7, but no true analgesia. Phantom pain not relieved. Effective relief after bilateral leucotomy but psychical deterioration (see p. 321).
58. James W. MGH U-685205BM	52	Traumatic mid-humeral amputation L. arm with severe cramping pain in phantom hand. Previous neurectomies in axilla without relief. Sympathetic block without relief.	1/50	C1*	C5	At 1 mo. pt. had some small patches of hypalgesia at C5, but he reports at 18 mos. that painful phantom is completely relieved and he has been working steadily

*Sensory level tested at operation.

tinued to be addicted to Demerol and finally required bilateral frontal leucotomy (see p. 321).

In the first case (Patient 45), whose phantom sensations had been present for 18 years, it is remarkable that relief from pain should have been so complete. After 27 months he wrote: "No sensation to speak of in the missing leg, but some throbbing at times in the little toe and ankle bone. No movement of the foot or toes. The operation has also eliminated

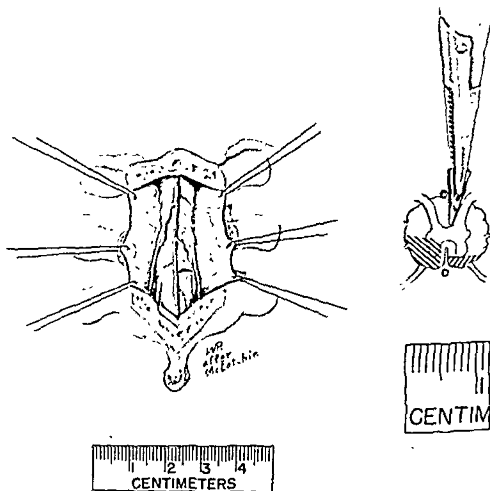


Fig 110 Position and extent of cordotomies in Patient 52.
Although there was analgesia to the seventh rib and reduction of touch, figure perception, and vibratory sensibility, the phantom pain remained unchanged.

the spasmodic jumping of the stump to almost 100 per cent." The second case (Patient 46) has had a sense of stiffness in his phantom ankle and big toe but no pain. The third (Patient 47) states that he has lost all sense of his phantom, but that when the muscles of his stump contract he is still aware of cramp-like sensations. In Patient 56 all sense of the phantom as well as pain in the stump have disappeared. It is of interest that this patient, who entered the hospital complaining bitterly of local pain

in the stump, admitted to equally disagreeable pain in the phantom foot only after her successful cordotomy. This was because so many previous doctors had told her that this complaint was purely psychoneurotic.

There was immediate failure in Patient 52, although analgesia was high and apparently complete. This man continued to have a sense of painful movement in his phantom thigh muscles following hip disarticulation for chondrosarcoma of the right femur with local recurrence in the acetabulum. He also complained that it felt as though his foot were pressed against a hot plate. The painful phantom persisted after two successive sections of the left spinothalamic tract, with a level of complete analgesia to the seventh thoracic segment. Subsequent section of the fasciculus gracilis and partial section of the anterior and anterolateral columns on the right side (Fig. 110) likewise failed. This operation resulted in a definite reduction of touch and figure perception on the right side of the abdomen, groin, and buttock, below T8. Vibratory sense was likewise abolished to the lower costal margin. The level of analgesia remained at T7 on the right, but the sensation of pin-prick was also eliminated below S1 on the left. The latter, however, soon recovered. Impairment in micturition necessitated an inlying catheter for a number of weeks. Final relief was achieved by bilateral frontal leucotomy (see p. 293).

It is of interest in connection with Patient 47 to point out that section of the spinothalamic tract does not relieve the uncomfortable sensation of muscle cramping. We have seen it fail four times: once in a patient with multiple sclerosis, a second time in an elderly woman with degenerative arthritis of the hip (see p. 267), and on the third occasion in a man with ankylosing arthritis and adhesive arachnoiditis of the cauda equina (see p. 266). Although all pain on movement was abolished in the last two individuals, they continued to suffer severely from muscle cramps. Indeed we have even seen one patient with lower thoracic metastatic carcinoma in whom painful cramps in the anterior abdominal wall persisted not only after a bilateral lower cervical cordotomy, but even after extension of the cancer caused loss of all touch, proprioception, and voluntary motor power below the costal margin as well.

Pool (1946) has sectioned the fasciculus cuneatus three times for cramping sensations in a phantom arm. In one case, followed for only a brief period, the result was satisfactory; after three months the other two were only partially relieved of their cramping pain and one continued to have so much "burning" pain that an added sympathectomy was performed. This likewise failed. In answer to a recent inquiry Pool has told us that he has no further enthusiasm for this procedure. Independently Browder and Gallagher (1946, 1948) have advocated section of the posterior column as preferable to anterolateral cordotomy in the cases where abnormal posture of

the missing limb is the prominent symptom. Their results in two upper extremity phantoms were equivocal, but in three out of four instances of painfully distorted phantom legs and feet they were distinctly promising Our single unsatisfactory experience is not sufficient to condemn the procedure, but in view of more promising results with spinothalamic tractotomy we must still recommend this as the operation of choice.

In the case of phantom pain following amputations of the upper extremity, relief by cordotomy is much more difficult to achieve. Falconer and Lindsay (1946) have recently reported two successful results. For such a high interruption of the pain tract the incision in the anterolateral column must be made at the second cervical segment, but in our hands this has failed to maintain a permanent level of analgesia above the uppermost outflow of the brachial plexus in two of our four attempts. This is illustrated by Patient 55 in Table XX. In this woman the pain of a phantom arm, disarticulated at the shoulder joint, was relieved for three months while the level of complete analgesia remained at the third cervical segment. Soon thereafter it fell, whereupon with only a high level of hypalgesia her original painful phantom returned. Patient 48, after a medullary tractotomy, was fully relieved for three years, only to have a return of symptoms with an unusually late fading of the analgesia. Patient 54 failed to derive any benefit from what appeared to be an adequate cordotomy. This leaves us with only the single satisfactory result in Patient 58.

Relief of pain in postamputation phantoms of the upper extremity therefore remains a major problem, chiefly on account of the technical difficulty of achieving the necessary high level of analgesia. In two of these cases (Patients 54 and 55) with forearm and shoulder amputations, previous resections of the postcentral cortex had been total failures. In Patient 55 anterior as well as posterior section of the plexus roots and also electroshock treatment had been tried and failed. A brief summary of Patient 54 is given below in the section on postcentral cortical ablations for phantom pain.

We believe that this series is sufficiently large to show that spinothalamic tractotomy can relieve a high proportion of painful phantoms, provided an adequate level of total analgesia can be maintained. For the arm, at least, this is a difficult problem. Yet we feel that transection of the anterolateral quadrant of the cord is more logical than section of the posterior column, at least when the chief complaint is severe pain rather than distorted position of the phantom. In view of the fact that there has been no lasting urinary impairment in any of our patients and no other serious complications except the disagreeable paraesthesias in Patient 50, we are still convinced that anterolateral cordotomy is preferable to leucotomy for the routine treatment of phantom pain, at least as far as the lower extremity is

concerned. In the case of the arm, especially after amputation at the shoulder, the value of the procedure must still remain *sub judice*.

5. Posterior Myelotomy

Several French surgeons have sought to relieve painful phantoms using this procedure. The patient of Lhermitte and Puech (1946) was, however, not helped following this operation on two occasions two years apart, as well as following resection of his opposite parietal lobe. Guillaume (1942) and Guillaume, Bertrand, and Mazars (1945) were at first encouraged by their results in this type of problem, but in 1949 Guillaume, de Sèze, and Mazars, after considering their experience with myelotomy, rejected it completely for painful phantoms in the upper limb because of postoperative respiratory difficulties and state that cordotomy is the operation of choice when the pain is referred to an absent lower limb.

For the rare cases of phantom limb in which the pain appears to be of central origin, the two following methods have recently been proposed for its surgical elimination:

6. Resection of the Sensory Cortex

According to Riddoch (1941), the phenomena of the phantom limb such as the persistence of pain and postural sensations which follow the amputation can be explained only on the basis of cortical activity. He stated that "destruction of the cortical sensory receptive mechanism in the parietal lobe, which is concerned with the development of postural and surface models and with the recognition of change, causes immediate abolition of the phantom limb." This theory was corroborated by the case reported by Head and Holmes (1911) in which disappearance of a postamputation phantom foot followed a vascular lesion of the opposite parietal cortex. Three more recent similar cases have been reported by Bornstein (1949), who had an opportunity to observe a large number of amputees in a prisoner-of-war camp in Germany during World War II. Three men with painful phantoms were relieved by (1) a self-inflicted wound in the opposite parietal cortex; (2) destruction of this area from metastasis of a hypernephroma, and (3) postictal cortical paralysis which periodically followed recurring epileptic seizures. With interruption of the corticothalamic connections, as pointed out by Gerstmann (1942) and Nielsen (1938), the patient may lose awareness that he possesses portions of the opposite side of his body. This is the antithesis of the phenomenon of the phantom limb and gives additional backing for the surgical ablation of sensory areas of the cerebral cortex.

Indirect evidence for the cortical origin of certain painful sensations which may complicate amputation is the fact that Michelsen (1943) has

reported five instances of pain produced by lesions in the postcentral cortex which we have observed on the neurosurgical service of the Massachusetts General Hospital. In one of these patients a depressed parietal fracture, causing irritation of the postcentral arm area, produced pain radiating down the opposite arm very similar to that experienced from a disagreeable phantom. By infiltrating the brachial plexus it was possible to obtain a complete motor and sensory paralysis, yet the pain which seemed to originate in the arm remained unaltered.

Leriche (1937A, p. 186) first suggested excision of the sensory centres of the cortex. In 1939 he injected procaine into the postcentral gyrus of a patient suffering from severe pain "of thalamic type" and gave the man relief for two months (1949, p. 293). But it was de Gutiérrez-Mahoney (1944) who put this theory to its first real test and who is primarily responsible for the systematic widespread trials of the effect of excision of sensory cortex. He carried out resections in the postcentral gyrus in four patients with painful phantom arms.* Although at first the results were encouraging, later follow-up observations have shown a return of disagreeable sensation in three cases out of four (1948). One of these has recently come in to the Massachusetts General Hospital seeking further help. Only the first patient, who had two fingers cut off by a circular saw, appears to have had a satisfactory lasting result. Perhaps this may be related to the limited area of cortex involved.

We have received reports of a number of other operations of this sort which are of interest to summarize briefly:

Lhermitte and Puech (1946) have published the report of a soldier of World War I with phantom pain following upper thigh amputation for gas gangrene. The result of cortical ablation of that part of the parietal lobe corresponding to the sensory domain of the phantom was nil in this case of longstanding narcotic addiction and psychic deterioration.

Horrax (1946) has reported resection of the postcentral arm cortex on both sides in a man suffering from painful phantom hands following bilateral forearm amputations for traumatic injury. At the second operation a small portion of the precentral gyrus was also excised because its stimulation produced pain, but these procedures gave only temporary relief.

A. S. Crawford and R. S. Knighton (personal communication 1952) have had a patient who suffered from carcinoma and a painful phantom in a lower limb. Following postcentral gyrectomy pain returned in the stump but not in the phantom before the patient died five months after operation.

---

*Resection of the postcentral convolution was suggested in the first case by the fact that the patient, who had convulsive seizures involving the amputated fingers, had relief of pain after each seizure.

Echols and Colclough (1947) reported the case of a 53-year-old man who developed gangrene of the left foot due to peripheral vascular disease which had failed to respond to lumbar sympathetic ganglionectomy. Following low thigh amputation there was prompt appearance of a painful phantom, and during the next two years he had been incessantly aware of his foot and toes being in a state of painful plantar flexion. Because spinal anaesthesia failed to relieve this sensation the cortical sensory representation of the foot was excised under local anaesthesia. Preceding the resection direct faradic stimulation of this area made the patient complain that his phantom foot felt hot. Under observation for 11 months he continued to have a satisfactory result. During the second year, however, and since the publication of this case report, the patient had a recurrence of his original pain following a fall in which the stump was severely bruised. Dr. Echols has written us that he re-explored this patient's cortex. He was able to reproduce unpleasant sensations on stimulating the motor and adjacent sensory convolutions even after a much wider excision which included not only the precentral leg area, but also a large part of the parietal lobe. After this the patient, who was under local anaesthesia, stated that his pain was again relieved. Unfortunately he died too soon after operation to evaluate the result. Nothing could better illustrate the vital importance, emphasized so frequently throughout this book, of prolonged follow-up after operations for relief of pain.

A second very similar disappointing end-result has been reported to us by Dr. Charles Troland. In this woman an amputation of the right upper forearm had been necessary for gangrene caused by a postoperative embolism of the brachial artery. Phantom pain, referred to the lower forearm and hand, developed in the hospital. The patient's life soon became unendurable because of a sensation as though her hand were being squeezed in a vise. On readmission six months later sympathetic blocks were performed without benefit. The left parietal cortex was exposed under local anaesthesia. When the postcentral gyrus was stimulated in the arm area the patient complained of intense pain in the right hand and stated that this reproduced the pain of her phantom limb. However, she also noticed the same sensation but with less intensity when the cortex was stimulated in front of the central sulcus in the motor arm area. The arm area in the postcentral gyrus was then excised subpially by suction. In the next six months this patient had no return of the disagreeable phantom, although she had some recurrence of stump pain. Dr. Troland ended this interesting account with the following wise conclusion, with which we are in complete accord: "I personally am inclined to believe that the phantom problem will not be solved until the entire sensory distribution of the affected limb can be isolated. Of course, I do not believe that this is possible at present because

of the widespread distribution of the sensory cortex." According to a still later report this woman is beginning to complain again of disagreeable phantom sensations.

Wertheimer and Mansuy (1949A) describe a patient whose phantom pains referred to a lower limb were almost gone following resection of only 2 sq. cm. of cortex in the gyrus behind the electrically excitable motor cortex. Follow-up at the time of the reporting of this case was only six months after operation, however.

Stone (1950) reported three patients operated on by Dr. John Martin, two with painful phantoms and one with central pain referred to an upper limb following a cerebral vascular accident. In the latter pain was still present following amputation at the shoulder. In each of these Martin's removal of appropriate portions of postcentral gyrus left the patient pain free at follow-ups 10 to 14 months later. These good results are the more remarkable in that comparatively small amounts of brain were removed in the two cases in which the extent was measured. This amounted to areas of only 1 cm. in width, 1 cm. in depth, and 2+ cm. in length in Case 1 and 1.5 cm. in length by 1 cm. width in Case 2.

Lenshoek (1949) has also reported three relatively successful efforts in handling phantom pain in the upper limb. In two of these the area of cortex resected lay in the parietal lobe but posterior to the postcentral gyrus. In the first of these both phantom sensation and pain after amputation of the upper arm were stopped. In the second, the phantom sensation returned, but spontaneous involuntary movements in the absent hand and fingers and the accompanying pain stayed away. In the third case some of the pain remained after removal of that part of the postcentral gyrus concerned with the arm in a patient whose limb was paralyzed and anaesthetic after avulsion of the brachial plexus.

Lewin and Phillips (1952) were encouraged to try this operation after witnessing the relief of painful epileptic attacks in the upper limb and face following 1 x 0.5 cm. resection of cortex adjoining an area of scar. The patient's painful attacks had been reproduced by stimulation of this area. In two patients with painful phantoms in lower limbs the removal of the corresponding part of the postcentral gyrus gave substantial but not complete relief at six months and five weeks respectively. Even after generous excision of postcentral gyrus the first patient continued to have some pain while still on the operating table.

Erickson, Bleckwenn, and Woolsey (1952) have carried out detailed mapping of the responses from the central gyri in three patients with painful phantom limbs. In the first patient pain in an upper limb was allayed ex-

cept for recurrence in the phantom thumb, the postcentral area for which had probably not been excised. For the remaining three months of life in this woman with osteogenic sarcoma the degree of relief was gratifying. In the second patient postcentral gyrectomy for the area of the upper limb had eliminated the pain in the phantom, but not that in the amputation stump at three months after operation. At five months he was found dead in a field, cause unknown. The third patient's phantom pain was in a lower limb and this has remained absent at a 13-month follow-up after postcentral gyrectomy. The spontaneous type of pain was reproduced at operation in the last two patients by *stimulation of appropriate areas in the parietal* lobe, and the pain disappeared in the last patient after removal of the postcentral block of tissue.

It is noteworthy that in this whole group of successes none has been followed for more than 14 months.

We have two cases to add to the series of postcentral resections of sensory cortex for painful phantoms of amputated upper extremities. Both were unsuccessful but valuable experiences:

Patient 51, Robert S., Worcester Hospital, was a 51-year-old man who had had a traumatic amputation of his forearm after his hand was crushed in an air compressor. The position of this painful phantom was exactly that in which he last remembered his hand, with the thumb and index finger extended, the others flexed, as he was in the act of tightening a valve. Associated with this was the sensation of holding a hot metal object in his palm together with burning pain in the tips of his thumb and index finger. This phantom developed immediately after the amputation and became unbearably severe. Local injections of procaine, removal of a neuroma, subsequent neurectomy of his median nerve, and finally revision of the stump near the lower end of the forearm had all failed to give him any lasting relief. He had attempted suicide.

For this reason a cortical resection of the entire gyrus in the postcentral area for hand and fingers was carried out under local anaesthesia by Dr. John T. B. Carmody and one of us on 1/9/46. This man was an unusually cooperative subject and it was therefore possible to carry out very complete mapping of the motor and sensory representation of his arm. This operation is illustrated by Figure 111 It was of interest that stimulation of sensory areas in his postcentral convolution gave rise usually to a crawling sensation in one or more of the phantom fingers, but only twice to actual pain. Painful responses did occur, however, on stimulation at points numbered 12, 13, and 14 in the precentral convolution, as illustrated in the drawing. Perhaps erroneously, it was decided not to resect this portion of the motor hand representation, which would have caused him no serious loss of motor control in view of the absence of the hand

The disagreeable phantom disappeared, but only for a period of several

of the widespread distribution of the sensory cortex." According to a still later report this woman is beginning to complain again of disagreeable phantom sensations.

Wertheimer and Mansuy (1949A) describe a patient whose phantom pains referred to a lower limb were almost gone following resection of only 2 sq. cm. of cortex in the gyrus behind the electrically excitable motor cortex. Follow-up at the time of the reporting of this case was only six months after operation, however.

Stone (1950) reported three patients operated on by Dr. John Martin, two with painful phantoms and one with central pain referred to an upper limb following a cerebral vascular accident. In the latter pain was still present following amputation at the shoulder. In each of these Martin's removal of appropriate portions of postcentral gyrus left the patient pain free at follow-ups 10 to 14 months later. These good results are the more remarkable in that comparatively small amounts of brain were removed in the two cases in which the extent was measured. This amounted to areas of only 1 cm. in width, 1 cm. in depth, and 2+ cm. in length in Case 1 and 1.5 cm. in length by 1 cm. width in Case 2.

Lenshock (1949) has also reported three relatively successful efforts in handling phantom pain in the upper limb. In two of these the area of cortex resected lay in the parietal lobe but posterior to the postcentral gyrus. In the first of these both phantom sensation and pain after amputation of the upper arm were stopped. In the second, the phantom sensation returned, but spontaneous involuntary movements in the absent hand and fingers and the accompanying pain stayed away. In the third case some of the pain remained after removal of that part of the postcentral gyrus concerned with the arm in a patient whose limb was paralyzed and anaesthetic after avulsion of the brachial plexus.

Lewin and Phillips (1952) were encouraged to try this operation after witnessing the relief of painful epileptic attacks in the upper limb and face following 1 x 0.5 cm. resection of cortex adjoining an area of scar. The patient's painful attacks had been reproduced by stimulation of this area. In two patients with painful phantoms in lower limbs the removal of the corresponding part of the postcentral gyrus gave substantial but not complete relief at six months and five weeks respectively. Even after generous excision of postcentral gyrus the first patient continued to have some pain while still on the operating table.

Erickson, Bleckwenn, and Woolsey (1952) have carried out detailed mapping of the responses from the central gyri in three patients with painful phantom limbs. In the first patient pain in an upper limb was allayed ex-

months. The phantom thumb then began to protrude again from his stump and within a few weeks the entire painful hand had reappeared. A high transection of the anterolateral spinal quadrant was therefore performed by Dr. Carmody on 6/1/48, with establishment of a satisfactory sensory level at C3. Despite the maintenance of analgesia including the neck, upper limb, and thorax, the phantom soon returned. Nine months later the patient felt he was as badly off as ever, with severe pain in the missing thumb and index finger and less acute representation of his other digits.

Patient 55, Marguerite M., MGH U-637760BM, represents another similar problem. This 48-year-old woman, following multiple local resections of neurogenic sarcoma from her upper arm, had undergone a scapulohumeral disarticulation at a nearby hospital in May, 1947. Three days later she became aware of her missing extremity. At first the sensation was not unpleasant as "it made you feel as though you still had your arm." Within a month, however, her hand felt as though it were tied up in severe cramps and when it drew up towards her shoulder the pain became unbearable. Posterior rhizotomy performed in the following July gave only temporary benefit for a period of three weeks. Postcentral corticectomy, which was carried out by the same surgeon four months later, failed to produce even transitory amelioration. She then entered the Massachusetts General Hospital seeking relief from her unendurable phantom and for epileptic seizures which developed from the cerebral cicatrix. The latter unfortunately responded poorly to anticonvulsant medication and she has continued to have intermittent seizures and one bout of status epilepticus. The phantom arm, drawn up in a twisted, flexed position at the wrist and elbow, was relieved by upper cervical section of the spinothalamic tract as long as the high level of analgesia remained complete. Six months later, when analgesia had been reduced to hypalgesia, the phantom had again become a cause of persistent discomfort.

The probable explanation of the ultimate failure in so many of these cases is the generally unrecognized extent of the sensory representation over a wide cortical area behind the postcentral gyrus as well as in and in front of the precentral area of motor control. Recently Cook and Druckemiller (1952) have hypothecated that the presence of a phantom limb is intimately associated not only with the gnostic (parietal) areas but must also be connected with the memories of past experience "filed" in the temporal lobe. It would seem to us most likely that persistence of phantom sensation is due to failure to resect the entire postcentral convolution from which the pain is supposed to be projected. Reference to Figure 111 reveals that such criticism is pertinent in our case, since the removal omitted a portion of the thumb area and the whole forearm area of the postcentral gyrus. *Because of the extensive area of cortex concerned with the appreciation of pain and the added risk of complicating epilepsy following cortical resection so close to the motor strip, we believe that this operation is not a*

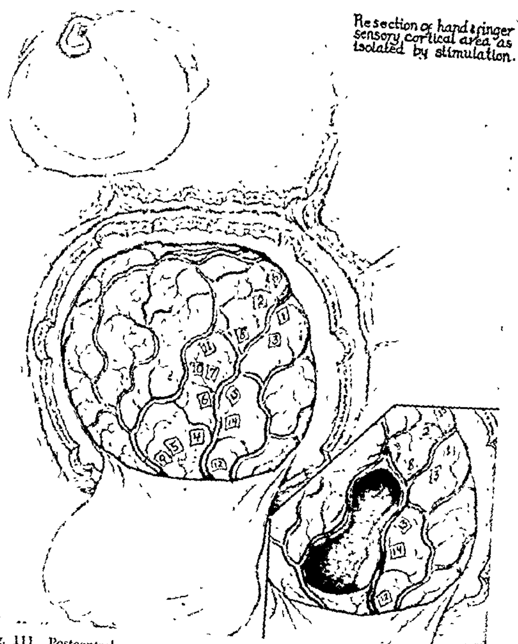


Fig. 111 Postcentral gyrectomy for painful phantom after forearm amputation. Complete failure to secure relief in Patient 54, Table XX. This operation was performed by Dr. J. T. B Carmody and one of us We are indebted to Dr Carmody for permission to reproduce this drawing of the operation and for the details of the cortical stimulation that follow:

1. Contraction upper lip.
2. Sense of tongue thickening.
4. Crawling sensation fingers 3 to 5.
5. Pain in ulnar border phantom hand.
6. Crawling in fingers 2 and 3.
7. Crawling in finger 2.
8. Crawling in thumb, peculiar sensation in mouth.
9. Crawling in thenar eminence
10. Crawling in thumb.
11. Crawling with pain in thumb
12. Flexion forearm with tingling and pain
13. Pronation and supination Pins and needles in arm. Fingers spread and hurt.
14. Tingling to pain in hand

though it were on a hot plate, and then radiated up the calf and adductor muscles of the thigh, where the patient complained of intense soreness and pain deep in his stump. There was recurrent tumour in the acetabulum. This patient's case history and previous operations, which should have interrupted all the ascending tracts in his spinal cord, have been summarized in Table XX and illustrated in Figure 110. The patient had been taking Pantopon in doses of 20 mgm. 4 i.d. without adequate relief.

Despite the extensive cordotomies and complete analgesia to the level of the nipple it remained apparent that the patient still had severe pain, with a disagreeable "sputtering" sensation in the muscles of his stump, which would build up to the point where muscular contractions and spasmodic pain became unendurable. He was then taking 40 mgm. of Pantopon by the clock every three hours.

1/29/47: Bilateral frontal leucotomy, using the Freeman and Watts technique, by Dr. J. S. Hodgson.

Recovery from this operation was satisfactory, although the patient was at first much disoriented and confused. He ceased complaining of the pain and twitching in his stump, but he still noticed pain in other areas, such as radiculitis connected with his cordotomies. At the time of his discharge to his home in the Middle West, four weeks postoperatively, he was requiring no medication and was able to enjoy the company of his wife and friends.

Follow-up letters from his wife, a highly intelligent school teacher, revealed that he had no disturbing psychic changes as the result of the leucotomy. He never spoke of the operations or of the suffering he had endured, but with the development of metastatic lesions in his chest he complained of new pain. His wife was, however, impressed by the fact that he expressed no concern over these manifestations, although he was aware of the fact that his disease had recurred and was rapidly approaching a fatal termination. "He regards his pain as a little child would. He is very noisy and suffers audibly, but as soon as the pain leaves he does not lie in wait for it to come back. He does not fall asleep worrying about how much suffering he will have to endure tomorrow." He finally died of his pulmonary metastases five months after the leucotomy. In his terminal illness, when he again required sedation because of pain in the chest and shortness of breath, his wife stated that its effect was much more satisfactory than before the leucotomy. Opiates then controlled his pain better and did not produce the former nervousness and apprehension.

The details of the second case, Patient 57 in Table XX, are given on p. 402. Following the bilateral leucotomy, although free of his former suffering, he has had to remain in a state institution because of severe psychological deterioration.

It will be seen that biliteral frontal leucotomy, although capable of relieving unbearable pain and morphine addiction, still leaves much to be desired. We hope that we shall find a better solution for future problems

desirable procedure. In view of the large number of poor long-term results from postcentral gyrectomy, we think that future excisions in this area, if tried at all, should extend as well to include at least parts of the precentral gyrus and of the parietal lobe behind the postcentral gyrus. Even this may not succeed—*vide* Echols's second operation on his patient and an experience of de Gutiérrez-Mahoney in which postcentral plus partial precentral gyrectomy did not stop the phantom pain. The latter author, the initiator of this procedure, has kept in touch with surgeons all over the world who have performed the operation and promises us next year a full account of the late results.

7. Release from States of Agitation and Introspection by Frontal Leucotomy

A final possible approach to the problem of the unbearable phantom is the elimination of the sufferer's introspection and self-centred concentration on his condition which is the natural outcome of long-standing intractable pain. While electroshock and psychotherapeutic methods alone have rarely been effective, bilateral frontal leucotomy has been found to accomplish this result. A successful operation of this type was first performed by W. P. Van Wagenen in 1941 (personal communication).* This patient had had a series of forty-five operations for chronic osteomyelitis, ending up with an amputation through the pelvis. He continued to have intractable pain in his phantom limb and was a confirmed alcoholic as well as morphine addict. In the years that have elapsed since the lobotomy Van Wagenen reports that he has remained free of any serious discomfort and has recovered from his drug addiction, but has to be confined to a state institution because of his tendency to assault young women, his continued craving for alcohol, and homicidal tendencies when drunk. The psychiatric changes of this historic case are given in further detail in Chapter IV.

We have two other examples to record, one of which has already been alluded to above as a failure of anterolateral and posterior column tractotomy (see p. 407). His case history is of so much interest that it deserves a detailed account.

Patient 52, Frank I., MGH U-552763PH, 51. In this case a somewhat unusual form of phantom sensation resulted following hip disarticulation 18 months previously for chondrosarcoma of the upper end of the femur. Preceding the amputation six local operations had been performed at other hospitals, and the ensuing phantom was unusual in that the patient felt his pain in the missing thigh as well as in the foot. Pain began in the sole as

*In so far as we are aware, this is the first case in which frontal leucotomy was undertaken for the relief of pain in organic disease (p. 287).

CHAPTER XIII

NEURALGIAS OF THE PERIPHERAL NERVES: PAINFUL SURGICAL SCARS, INTERCOSTAL NEURALGIA, MERALGIA PARAESTHETICA, GANGRENE OF DIGITS, AND DEGENERATIVE ARTHRITIS OF THE HIP

In addition to the peripheral neuralgias that have been discussed in the preceding chapter, there remain a wide variety of painful conditions which arise from injury or disease involving the nerves of the extremities, major joints, thoracic and abdominal parietes. To be discussed in this chapter are the painful operative scars, neuralgia of the lateral femoral cutaneous and intercostal nerves, and pain arising from occlusion of peripheral arteries and degenerative arthritis of the hip. Conditions such as cervical rib, the scalene syndrome, and sciatica from herniation of intervertebral discs are not included, because it is possible to remove the source of the pain. Methods of dealing with pain arising from malignant tumours of the extremities will be taken up in Chapter XVIII.

A. PAINFUL SCARS

Pain in abdominal and thoracic scars which follow wounds or surgical incision is caused by neuromas, either in continuity or the characteristic end-bulb variety discussed above in connection with postamputation neuralgia. Persistent paraesthesia and intense discomfort occasionally result after abdominal operations, especially in connection with herniorraphy scars. We have been forced to intervene in a number of cases of this sort. Simple infiltration with procaine of the iliohypogastric and inguinal nerves at the anterior-superior spine of the ilium gives prompt but temporary relief. One elderly woman, however, has remained free of pain for over two years after injection of the nerves with a long-lasting local anaesthetic in oil (Rectocaine). This procedure is so simple to use in cases where there are good landmarks for accurate injection that it deserves further trial. Injection of alcohol, however, is not advisable because it often results in a disagreeable neuralgia of its own. Surgical division of the iliohypogastric and inguinal nerves has rarely been effective (Table XXI). In two patients so treated recurrence took place after very short intervals (Patients 4 and 10). Another patient, treated by division of these nerves proximal to the scar and painting their ends with methyl methacrylate, failed to derive any

of this sort, either by a less extensive procedure related to the cerebral cortex or a stereotactically controlled operation on more centrally located areas. How some physicians can still recommend leucotomy before they have explored the possibility of cordotomy is difficult to understand. Kolb (1950), for example, reports a man who was treated for a painful phantom of the lower extremity by a primary bilateral frontal leucotomy. This individual was relieved of his pain, but months later continued to embarrass his wife by such asocial behaviour as urinating in the street while she was waiting with him for a bus.

5. Louis D. MGH U-44659 (Dr. J. Michelsen)	34	Old scar from drainage of empyaema.	Intercostal neuralgia. Previous proximal section of intercostals 1 to 6 with relief for 6 mos.	3/43	T3-T6	T3-T6		Incomplete relief at 4 mos.
6. Henry P. Sgt. USMC (U.S.N.H., St. Albans)	32	7th and 8th ribs fractured by shell explosion.	Intercostal neuralgia.	11/45	T7-T11	T7-T11	Mild sepsis in incision.	Good relief at 7 mos.
Operations at Site of Nerve Injury (4 cases)					*Type of Operation*			
7. Shirley C. MGH U-389897 BM	20	Severe crush of anterior chest in auto accident 2 yrs. previously.	Intercostal neuralgia with persistent pain at costochondral junction	1/43	Crushing of intercostal nerves 4 to 9			Return of pain in 3 mos.
8 Henry H. Pvt USMC (U S.N.H, St. Albans)	20	Gunshot wound of 10th rib with injury and scarring of intercostal nerve.	Intercostal neuralgia with 3 cm band of hyperaesthesia	3/43	Resection of neuroma with end of nerve drawn through drill hole in rib			Good result at 2 mos.
9. Case of Dr. L. Soutter	40	Empyaema drained in childhood with recent onset of severe pain after heavy lifting.	Intercostal neuralgia at site of old incision.	1950	Excision of neuroma of intercostal nerve.			No relief, but gradual improvement with physiotherapy.
10. William T. MGH U-620850 BM	57	Incisional neuralgia after repair of inguinal hernia.	Burning pain and hyperaesthesia in area of iliohypogastric and ilioinguinal nerves, a serious problem at night.	6/6/48	Diagnostic procaine block			Transitory relief.
				6/18/48	Neurectomy central to scar			Relief for 10 days, then sudden recurrence. Followed 1 yr

*Sensory level tested at operation.

TABLE XXI

PAINFUL SCARS FOLLOWING TRAUMATIC LACERATION AND SURGICAL INCISION

Patient	*Age*	*History*	*Pain Reference*	*Date*	*Level of Operation*	*Side*	*Sensory Level*	*Complications*	*Result*
Spinothalamic Tractotomy (3 cases)									
1. Jeannette S. MGH U-10469	31	3 upper thoracic sympathectomies for recurrent Raynaud's disease. No relief following posterior rhizotomy.	R. occiput, neck, shoulder, and breast. Psychoneurotic, morphine addict.	10/40	Bulbar*	L.	Hypalgesia C2 Analgesia T1	Temporary ataxia with functional exaggeration.	Postoperative ataxia slowly disappeared. Complete relief at 10 yrs.
2. Christine H. MGH U-274289	25	2 upper thoracic sympathectomies on each side for recurrent Raynaud's disease.	R occiput, neck, shoulder, arm, and upper chest.	3/49	C1*	L.	Hypalgesia C3 Analgesia T1	Functional loss touch and position sense with weakness of analgesic leg, which disappeared at 3 mos.	Complete relief at 2¾ yrs. but similar neuralgia developed on opposite side.
				10/50	C2*	R.	Hypalgesia C5 Analgesia T1	Slight weakness R. leg and chronic cystitis.	Pain free at 10 mos.
3 Ada P. MGH U-514799	30	Inguinal scar following postphlebitic vein ligation with injury to branch of anterior femoral nerve. No relief following: 1) lumbar ganglionectomy, 2) resection of nerve caught in scar, 3) crush of saphenous nerve at knee.	Anterior surface of thigh and medial calf to ankle.	11/48	T1*	R.	T8	Weakness anterior leg muscles, requiring brace for foot-drop, but works as nurse.	Complete relief at 18 mos. Residual weakness foot extensors.
terior Rhizotomy (3 cases)									
rles M. ;H U-271252	33	Inguinal herniorrhaphy. No relief following neurectomy of iliohypogastric and inguinal nerves.	Groin and scrotum.	3/41	T11-L2		T11-L2	Collection of cerebrospinal fluid beneath incision. Pain in laminectomy incision.	Relieved at discharge, but pain soon recurred. Followed 6 yrs

5. Louis D. MGH U-44659 (Dr. J. Michelsen)	34	Old scar from drainage of empyaema.	Intercostal neuralgia. Previous proximal section of intercostals 1 to 6 with relief for 6 mos.	3/13	T3-T6	T3-T6		Incomplete relief at 4 mos
6. Henry P. Sgt. USMC (U.S.N.H., St. Albans)	32	7th and 8th ribs fractured by shell explosion.	Intercostal neuralgia.	11/45	T7-T11	T7-T11	Mild sepsis in incision.	Good relief at 7 mos.
Operations at Site of Nerve Injury (4 cases)					*Type of Operation*			
7. Shirley C. MGH U-389897 BM	20	Severe crush of anterior chest in auto accident 2 yrs. previously.	Intercostal neuralgia with persistent pain at costochondral junction	1/43	Crushing of intercostal nerves 1 to 9.			Return of pain in 3 mos.
8. Henry H. Pvt. USMC (U.S.N.H., St. Albans)	20	Gunshot wound of 10th rib with injury and scarring of intercostal *nerve.*	Intercostal neuralgia with 3 cm. band of hyperaesthesia.	3/43	Resection of neuroma with end of nerve drawn through drill hole in rib.			Good result at 2 mos.
9. Case of Dr. L. Soutter	40	Empyaema drained in childhood with recent onset of severe pain after heavy lifting.	Intercostal neuralgia at site of old incision.	1930	Excision of neuroma of intercostal nerve.			No relief, but gradual improvement with physiotherapy.
10. William T. MGH U-620850 BM	57	*Incisional neuralgia after repair of inguinal hernia*	*Burning pain and hyperaesthesia in area of* iliohypogastric and ilio-inguinal nerves, a serious problem at night.	*0/0/48*	*Diagnostic procaine block.*			*Transitory relief.*
				6/18/48	Neurectomy central to scar.			Relief for 10 days, then sudden recurrence. Followed 1 yr

*Sensory level tested at operation.

benefit. Posterior rhizotomy, carried out in Patient 4 after resection of the neuromas in the herniorraphy scar had failed, was also ineffective.

In dealing with future cases of this sort we plan to give a thorough trial to block with procaine in oily solution; if unsuccessful, to encase the iliohypogastric and inguinal nerves, after section proximal to the scar, in a short length of polyethylene tubing. This method of sealing the end of a nerve in a nonirritant plastic sleeve was suggested to us by Dr. William V. Cone (personal communication). The tubing comes in a wide variety of sizes and can be sealed at the end by crushing with a heated haemostat. This is such a simple procedure that it seems well worth a trial. The patient, however, must be warned that likelihood of success is not great. Our limited experience with these painful scars has shown that the results of neurectomy are far from certain, no matter what method of treatment is adopted to prevent re-formation of neuromata.

Experience with five cases of disabling intercostal neuralgia has taught us a similar lesson. Resection of neuromas and proximal neurectomy failed to give any lasting relief in Patients 7 and 9, although burying the end of the intercostal nerve in a hole drilled in the rib was successful in Patient 8 up to the time he was last seen. A two-month follow-up in a case of this sort, however, gives little reassurance of enduring success. Posterior root section was followed by considerable return of pain in Patient 5, but was still affording relief of symptoms in the next patient at seven months (again too short an interval to predict permanent results). *We must therefore conclude that all local procedures, and even posterior rhizotomy, are at best an uncertain solution for postoperative or post-traumatic neuralgias of the thoracic and abdominal nerves. A single attack on the neuroma may be justified to satisfy the patient and his surgeon that no simple measure can rid him of his pain.*

In contrast to rhizotomy, spinothalamic tractotomy is a radical but certain solution. We have finally been driven to it in the three cases summarized in Table XXI. These are of such special interest that they deserve description in greater detail.

Patient 1, Jeannette S., MGH U-10469, a young woman of 29, had become chronically incapacitated and suffered a serious neurosis following multiple operations for Raynaud's disease in the upper extremities. Laminectomy and division of the second and third thoracic posterior roots, which had already been cut within the intervertebral foramen at the time of the preganglionic sympathectomy, had no effect on her pain. The postoperative neuralgia in this case ultimately spread to involve the occiput, neck, shoulder, upper back, and chest on one side. It was effectively relieved by section of the spinothalamic tract in the medulla. Complete rehabilitation required a supplementary course of psychotherapy for relief of drug

addiction and malnutrition. Ten years later she remained symptom free, but then started to complain of pain in the operative scars on the opposite side and to take Demerol for its relief. This was the first successful use of medullary tractotomy and has been published by White (1941) (see Table VIII, p. 277).

Pain in an exactly similar case has recently been relieved by tractotomy just below the level of the foramen magnum:

Patient 2, Christine H., MGH U-274289, 25: This second young woman was effectively relieved of her right-sided neuralgia with analgesia complete up to the third cervical dermatome and a high-grade hypalgesia which included the occiput and ear. It was fortunate that the patient was awakened and cooperated well in testing of her sensory level. After the first incision into the cord to a depth of 4 mm. analgesia had not reached the upper brachial segments, but when the cut was deepened and carried more ventrally a maximum high level was obtained. Normal urination was present when she got up on the sixth postoperative day, and there was no involvement of the pyramidal tract or complicating ataxia, which was a transitory but troublesome complication in Patient 1, where the medulla was incised at the level of the obex.

At 18 months after operation this young woman, a rollerskater on the vaudeville stage, was able to skate again without any ataxia or motor impairment. At this time, however, she began to complain of a similar neuralgia radiating from the sympathectomy scars on the opposite side. During the next year this steadily increased, to the point that she was again incapacitated and becoming addicted to Demerol. Unilateral frontal leucotomy was therefore tried, but with only brief benefit (see p. 302). We were most reluctant to advise a second leucotomy and finally, in desperation, resorted to a second cordotomy, which was carried out on the right side in October, 1950, at a point just caudal to the emergence of the first cervical anterior root (the previous section had been made just rostral to this). Analgesia on testing reached the second cervical segment. An otherwise smooth convalescence was complicated by a striking hypotension. For the first week her blood pressure in bed averaged 70/40, and when she first got up there was a postural fall to a syncopal level. This could be corrected by elastic bandages and a tight abdominal support. Five weeks after operation her blood pressure remained above 100 systolic. She required an inlying catheter for three weeks on account of incomplete emptying of the bladder, then began to void normally without residual urine but with occasional incontinence. At discharge the recent cordotomy had resulted in hypalgesia to C3 and analgesia to C8, while on the original side the levels were similar, but the degree of hypalgesia in the cervical dermatomes was less pronounced. At a follow-up examination four months later she remained free of all her former pain and was able to void normally, but she complained of some bouts of cystitis and occasional incontinence of urine Most unfortunately,

benefit. Posterior rhizotomy, carried out in Patient 4 after resection of the neuromas in the herniorraphy scar had failed, was also ineffective.

In dealing with future cases of this sort we plan to give a thorough trial to block with procaine in oily solution; if unsuccessful, to encase the iliohypogastric and inguinal nerves, after section proximal to the scar, in a short length of polyethylene tubing. This method of sealing the end of a nerve in a nonirritant plastic sleeve was suggested to us by Dr. William V. Cone (personal communication). The tubing comes in a wide variety of sizes and can be sealed at the end by crushing with a heated haemostat. *This is such a simple procedure that it seems well worth a trial.* The patient, however, must be warned that likelihood of success is not great. Our limited experience with these painful scars has shown that the results of neurectomy are far from certain, no matter what method of treatment is adopted to prevent re-formation of neuromata.

Experience with five cases of disabling intercostal neuralgia has taught us a similar lesson. Resection of neuromas and proximal neurectomy failed to give any lasting relief in Patients 7 and 9, although burying the end of the intercostal nerve in a hole drilled in the rib was successful in Patient 8 up to the time he was last seen. A two-month follow-up in a case of this sort, however, gives little reassurance of enduring success. Posterior root section was followed by considerable return of pain in Patient 5, but was still affording relief of symptoms in the next patient at seven months (again too short an interval to predict permanent results). *We must therefore conclude that all local procedures, and even posterior rhizotomy, are at best an uncertain solution for postoperative or post-traumatic neuralgias of the thoracic and abdominal nerves. A single attack on the neuroma may be justified to satisfy the patient and his surgeon that no simple measure can rid him of his pain.*

In contrast to rhizotomy, spinothalamic tractotomy is a radical but certain solution. We have finally been driven to it in the three cases summarized in Table XXI. These are of such special interest that they deserve description in greater detail.

Patient 1, Jeannette S., MGH U-10469, a young woman of 29, had become chronically incapacitated and suffered a serious neurosis following multiple operations for Raynaud's disease in the upper extremities. Laminectomy and division of the second and third thoracic posterior roots, which had already been cut within the intervertebral foramen at the time of the preganglionic sympathectomy, had no effect on her pain. The postoperative neuralgia in this case ultimately spread to involve the occiput, neck, shoulder, upper back, and chest on one side. It was effectively relieved by section of the spinothalamic tract in the medulla. Complete rehabilitation required a supplementary course of psychotherapy for relief of drug

The problem of this painful and damaging condition is solved by crushing the peripheral nerves at a point some six inches above the ankle. This procedure was developed by Smithwick and White (1930, 1935) and its value recently emphasized by Shumacker (1948B). The surgical technique is described on page 171 and photographs of a persistent painful ulcer, which followed toe amputation for thromboangiitis obliterans, relieved by this method, are reproduced in Figure 112. *This simple operation has resulted in an appreciable reduction of major amputations at the Massachusetts General Hospital. Not only is the pain relieved, but there is maximal vasodilatation within the anaesthetic zone which lasts for a period of several weeks.* The nerves always regenerate completely within a few



Fig. 112. Peripheral neurectomy in painful gangrene

Pain from an indolent ulcer following toe amputation in a case of thromboangiitis obliterans relieved by surgical exposure and alcohol injection of posterior tibial, superficial and deep peroneal nerves. Area of anaesthesia, which lasted several months, is illustrated.

From Smithwick and White: *Surg. Gynec. & Obst*, 1930, by permission of the editor.

this complication increased to the extent that she developed a hypertonic bladder of small capacity because of chronic infection. At 20 months the cystitis still remained resistant to treatment by the urological service.

Patient 3, Ada P., MGH U-514779, 30, a trained nurse, had been admitted to the hospital many times for phlebitis recurring in her left leg since 1942. Ligation of the femoral vein in 1943 and lumbar sympathetic ganglionectomy performed in 1945 had failed to improve the underlying condition. She developed aching, burning pain along the distribution of the medial sensory branches of the femoral nerve.

6/47: Exploration of the scar below the groin and excision of 2 cm. length of small nerve caught in the cicatrix. This gave transitory relief, but pain soon recurred, especially along the medial aspect of the calf.

9/48: Saphenous nerve crushed at level of knee. This gave only transitory relief and the patient was soon again incapacitated by pain and tenderness whenever a "trigger area" was touched on the inner aspect of her calf. She stated that she was unable to work or even to bear the nagging pain at rest. She had been thoroughly studied by the psychiatrists in the hope that cordotomy could be avoided, but finally this operation was forced upon us.

11/48: Right spinothalamic tractotomy at T1. The operation was performed under local anaesthesia and the level of sensory loss tested on the table. It was fortunate that this was done because pricking with a pin after the first incision brought out a level only to the iliac crest, and it required two further and deeper sections to secure satisfactory analgesia to the seventh rib. Convalescence was smooth with rapid return of bladder control. There was effective loss of pain and temperature sensation to the eighth rib and the patient was relieved of all her leg pain. Her only complaint was of slight residual weakness in the right anterior tibial muscle and toe extensors. When last seen five months afterwards she was ready to resume her nursing career, but still required a brace to prevent toe drop.

B. THREATENED GANGRENE OF EXTREMITIES

In certain patients with thromboangiitis obliterans painful gangrene of the toes may jeopardize an entire extremity. The reason for this is that minor open amputations of digits are often so painful that the patient cannot tolerate dressings or postural exercises; he loses sleep and appetite, is likely to become addicted to opiates, and his combined physical and psychical deterioration forces the surgeon to perform a high amputation. If only the pain can be relieved and the accompanying vasoconstrictor reflexes eliminated, the extremity can often be preserved over a period of acute thrombosis until a satisfactory collateral circulation develops. Excision of the lumbar sympathetic ganglia is useless under the circumstances, as pain does not ascend by this route and vasodilatation is usually inadequate to relieve the painful ischaemia of the semigangrenous area.

C. PAIN OF INTERMITTENT CLAUDICATION

In addition to the pain which occurs at rest in advanced arterial disease, intermittent claudication can also be relieved by peripheral neurectomy. As Slessor and Learmonth (1949) point out, "a muscle which is paralysed cannot claudicate." For the typical severe pain on walking which occurs in the calf muscles in certain cases of occlusive vascular disease, they recommend denervation of the gastrocnemius and part of the soleus. This can be done, as recommended by Jepson (1948), by an anatomical dissection of the posterior tibial nerve and cutting those branches that supply the affected gastrocnemius and soleus muscles through an incision in the popliteal fossa and upper calf. Care must be taken in all such operations in an ischaemic limb to produce minimal trauma, lest the incision fail to heal. According to Jepson, the muscle giving rise to claudication can be identified by injecting hypertonic saline. If pain is produced in the back of the knee its origin is usually in the gastrocnemius, whereas pain from the soleus is likely to be referred to the heel. Pain evoked by testing can be quickly relieved by injecting procaine. We have had no experience with this method, which appears to be a very simple and practical one. Slessor and Learmonth, who are authorities on peripheral vascular disease, state that the operation is suitable for patients who have only slight evidence of distal ischaemia, and is one of choice for early arteriosclerotics who cannot be improved by sympathectomy. The patient need only stay in bed a day or two and disability is slight when activity is already restricted by arterial obliteration. In their 30 cases "claudication distance has been substantially increased."

D. SENILE ARTHRITIS OF HIP

Malum coxae senilis may become a cause of incessant nagging pain. With every movement of the hip the degenerate joint creaks and sends twinges of pain to the buttock and knee. In addition, spasm of the muscles may make it impossible for the diseased joint to remain at rest. Under these circumstances it is essential to give the patient relief. If the general condition permits, cup arthroplasty, devised in this hospital by Dr. M. N. Smith-Petersen, is unquestionably the procedure of choice. Unfortunately some patients are too old or too poor surgical risks for the prolonged anaesthesia and manipulation of the hip required in this procedure. A few continue to suffer unremitting pain after an otherwise satisfactory arthroplasty. Recourse may then be had to sensory denervation of the hip joint.

The obturator nerve supplies the larger part of the anterior capsule of the joint (Kaplan, 1948). Irritation of this nerve is the cause of pain so often referred to the knee and the spasm of the adductor muscles. Follow-

months, but the time elapsed is often sufficient for opening up an effective collateral circulation. During this period of anaesthesia the patient can carry out intensive Buerger exercises and the surgeon can trim away necrotic sloughs to encourage healing by granulation. The result of the temporary interruption of vasoconstrictor fibres is also a help in selecting suitable cases for lumbar sympathectomy to ensure a lasting dilatation of the peripheral vascular bed.

On similar principles Atlas (1950) has advocated saphenous neurectomy for the relief of painful indolent varicose ulcers on the medial side of the lower leg and internal malleolus. The discomfort is often a direct factor in their resistance to therapy, as it prevents local medication and regional



Fig 113. Peripheral neurectomy in painful gangrene.
Painful ischaemia of finger-tips in case of advanced scleroderma, which was relieved by crushing digital nerves in distal portion of hand

compression. Following anaesthesia there has been rapid healing in this author's four reported cases. We also have had gratifying results after this simple procedure and found it equally useful to crush the sural nerve for relief of chronic painful ulcers over the lateral malleolus.

We have carried out a similar procedure for excruciatingly painful gangrene of the fingers due to scleroderma (Fig. 113). In this operation the digital nerves were crushed through a transverse incision in the distal flexion crease of the palm. The pain was effectively relieved, but the patient died of an associated bacterial endocarditis, which gave rise to vegetations on the aortic valve and a fatal cerebral embolus.

elderly woman with coronary disease was too poor a risk for arthroplasty, and even the thought of a cordotomy caused us grave misgivings. We therefore decided on peripheral sensory denervation.

9/8/47: Obturator neurectomy (intrapelvic section) released the adductor spasm and much of the pain in her knee, but pain continued in the back of her hip. At this stage the orthopaedic service attempted to straighten her knee by traction, but a small pulmonary infarction prevented further immobilization.

9/25/47: Section of sciatic sensory ramus to hip joint. This operation gave a very successful immediate result. The patient was able to get out of bed and move her arthritic hip freely and without pain. She was taken off morphine. There remained only a small area of hypaesthesia in the center of her inner thigh, and she noticed moderate weakness of movement in adduction. After discharge to her home in Maine, however, there was a gradual recurrence of some of her former pain, although at nine months she wrote that the adductor-flexor spasms had never returned. At 10 months her doctor reported that she had satisfactory relief from her former muscle spasm and her worst pain. She was leading an active wheelchair existence, which had been impossible before the neurectomies.

Another bedridden patient of Dr. Robert Joplin, *Alice N.*, MGH U-650654BM, 71, was relieved of much but not all of her former pain by obturator neurectomy and section of the sciatic ramus to the hip. Relief after two months was sufficient to permit her to get about with the aid of crutches.

A third woman, *Annabelle E.*, MGH U-179749, 58, operated upon by Dr. Joplin, maintained an excellent result at the end of 19 months and was able to walk comfortably with a cane. Pain could still be induced on extreme movements of the hip.

In a fourth patient, *Chester K.*, MGH U-594358BM, we obtained a similarly happy early result only to have the pain soon recur. He has since had a cup arthroplasty performed by Dr. Joseph S. Barr with a brilliant result.

When the patient is too poor an operative risk to permit safe correction of the lesion by reconstruction of the hip, but not in such bad general condition as the patients cited above, we recommend anterolateral cordotomy, at least if only one hip requires denervation. This policy should also apply to those individuals who have had an arthroplasty performed without sufficient relief. The operation, when performed unilaterally and by an experienced surgeon, causes very little upset to the patient and should ensure complete relief of pain that is so incapacitating. This is illustrated by the following case:

Vincenzo P., MGH U-571882, a 63-year-old Italian, suffered a severe contusion of the left hip in an automobile accident in 1943. Although there were no immediate complications, he developed severe hip pain with external rotation two years later. Pain radiated downwards to the knee and soon became

ing the original suggestion by Camitz in Sweden in 1933 many neurectomies have been performed, especially in France. After obturator section, described on p. 173, there is only a small patch of cutaneous hypaesthesia in the medial mid-thigh and follow-up x-ray films have shown no tendency of the denervated joint to develop trophic changes. Tavernier and Godinot (1945) recommended supplementary division of the sciatic ramus to the posterior capsule of the joint. This nerve supplies the obturator internus, inferior gemellus, and quadratus femoris muscles, but paralysis of these and also of the adductor longus and brevis (innervated by the obturator nerve) will not interfere seriously with the patient's ability to walk. Residual innervation of the adductor magnus muscle by lower fibres from the sciatic nerve will still permit fair power of thigh adduction.

In the 54 patients submitted to obturator neurectomy at the Hospital for Joint Diseases in New York reported by Kaplan (1948) only one-third had good results; 80 per cent of Key and Reynolds' 20 patients showed some improvement (Key and Reynolds, 1948). In an unreported series of 48 cases from Buffalo by Dr. B. E. Obletz (personal communication), most of whom were submitted to both obturator neurectomy and sciatic ramisectomy, approximately similar results were obtained. Puechberty (1947), who in his thesis for the University of Toulouse reviewed the results in 10 patients of Rieunau with both obturator and sciatic denervation, has reported six failures, two slightly improved, and only two satisfactory results. It is therefore obvious, as Puechberty concluded, that *section of these two nerves does not bring about a complete sensory denervation of the hip joint. Joints have a very extensive innervation and, in the case of the hip, accessory sensory fibres must be derived from the femoral and possibly from the lateral and posterior femoral cutaneous nerves as well. This procedure should be reserved for cases that are too poor risks for either an arthroplasty or cordotomy, as the likelihood of effective relief is not great.*

We have had a limited experience of cutting the obturator nerve where it enters the notch in the pubic ramus and also the sciatic ramus to the joint from behind. The following case histories are examples of this:

Jenness W., MGH U-332810BM, 74. Malum coxae senilis. Pain in the left hip due to senile arthritis had been a cause of grumbling discomfort for 10 years. During the past six weeks the pain had become much more severe, with radiation to the knee as well as to the hip joint. Muscle spasm developed with the pain and was brought on by any movement of the hip or touching the anterolateral thigh. There was not only severe pain, but the patient was bedridden by limitation of hip movement and deformity in adduction and flexion. She required morphine in 20 mgm. doses four to six times a day. X-rays showed typical degenerative arthritis. This obese

"From that date, on standing or walking, this region becomes the seat of a variety of perverted sensations, described as 'tingling, like striking the crazy-bone,' 'tenseness and tearing,' and formication. Sometimes there are darting feelings 'like the bursting of a bubble,' sometimes a dull, deep pain or ache when the leg is tired. These manifestations often begin as a glowing sensation in the part. They cease generally on sitting or lying down, but may recur in such attitudes on over-stretching or violently twisting the leg. Deep pressure with the hand over the part may bring them on. The patient is always aware of something wrong there on standing or walking. These sensations are felt every day and interfere with his habits of exercise ....

"On inspection it is apparent that the area complained of corresponds strictly to the distribution of the cutaneous filaments of the external cutaneous femoral nerve. . . . On testing with the needle-point the whole area is found to be far less responsive than normal, and towards the lower portion, just above the patella, anaesthesia is complete. A similar condition is demonstrated on the application of various tests, the tip of the finger, pinching, scratching, and slight pressure. There is little difference in sensation in both legs on deep pressure. The whole area appreciates the application of hot water in a diminished degree, and the lower third is wholly insensible to it."

Excellent descriptions of meralgia paraesthetica have been published since by Stookey (1928B), Lee (1936), Ecker and Woltman (1938), and Corlette (1944). One hundred and fifty cases have been seen at the Mayo Clinic, about three in each 10,000 general admissions. The most common etiological factor is an abnormal arrangement of the nerve as it emerges from the fascia under Poupart's ligament just medial to its attachment to the anterior superior spine of the ilium. Here the nerve may be compressed and angulated, so that it is placed under tension as the individual stands and walks. There are, however, numerous other factors which have been well described by Ecker and Woltman and also by Lee. These comprise local obesity, pressure from belt, corset, or truss, retroperitoneal irritation of the nerve as it crosses the iliacus muscle after emerging from the lateral margin of the psoas, and radicular injury within the spinal canal or intervertebral foraminae, by caudal neoplasms, arachnoidal adhesions, protruded discs, arthritic spurs, and other forms of vertebral pathology.

While many cases may subside spontaneously or after correction of local irritative factors, and the majority never cause more than minor complaints, a small proportion demand neurosurgical intervention. Ecker and Woltman (1938) stated that "resection of the nerve is now the standard operation for the condition, and the result usually is completely satisfactory"; Lee advocated a neurolysis with freeing and straightening the course of the nerve if it is found to be angulated. From our own unsatisfactory experience and observations of the poor results of other surgeons, we believe that both neurolysis and neurectomy often fail, as they do in attempts to relieve other forms of neuralgia in partially injured nerves.

severe on any movement, so that walking was extremely difficult. When he entered the hospital there was posterior tenderness over the left hip, extreme limitation of movement, and muscle spasm. Cordotomy was performed by Dr. B. Selverstone on 6/27/47. This patient was able to be up the next day and voided with a 270 cc. residual. The residual urine was reduced to a negligible quantity on the fourth day, and he remained free of pain with complete analgesia to T10 until last seen at 19 months. At this time he was able to walk without any pain in the left hip, but was developing mild pain from similar involvement on the opposite side.

In another elderly woman, *Mary Y.*, MGH U-606632, 70, with Paget's disease, a wedge fracture of T11 vertebra, advanced arteriosclerosis, and degenerative arthritis, pain on movement of the hip has also been relieved without any complication by anterolateral cordotomy with an analgesic level at T5. The joint creaks, but can be moved without pain. She continues, however, to have bouts of muscle spasms which give rise to real discomfort. This persistence of cramping pain in the muscles was no surprise to us, as we have seen it persist in cases of spinal disease submitted to spinothalamic tractotomy and believe that the sensation is not transmitted in the anterolateral columns, but perhaps in the posterior columns or by short chain conduction in the posterior horn of grey matter. If these symptoms persist to an unbearably severe degree, it should be possible to eliminate the irritable contractions of the adductor and hamstring muscles by obturator neurectomy and a Stoeffel denervation of the upper sciatic motor rami.

Although we have not yet resorted to neurosurgical procedures for relief of veterans with degenerative arthritis following missile wounds, where extensive local surgery might light up a former infection, we feel certain that these individuals can be safely relieved of their nagging pain by a section of the anterolateral column, carrying the analgesic level to the umbilicus.

E. MERALGIA PARAESTHETICA

Neuralgia of the lateral femoral cutaneous nerve was described in the year 1895 on March 15th by Bernhardt and on April 1st by Roth (1895). A graphic clinical description was given in this country in 1906 by Dr. James C. White, professor of dermatology at Harvard Medical School and chief of that service at the Massachusetts General Hospital.*

"The patient, a gentleman 55 years old, became aware of abnormal sensations in the skin of the lower two-thirds of the right thigh after an ordinary walk of four or five miles, whilst at Bar Harbor, Maine. The feelings were of a tingling nature. On examination there seemed to be a tenseness, as he described it, of the area mentioned, and the touch of a single finger seemed to be felt over an unusually large surface.

*White, J.C. (the elder): Meralgia paresthetica *J. Cutan. Dis.*, New York, 24:160-163, 1906.

"From that date, on standing or walking, this region becomes the seat of a variety of perverted sensations, described as 'tingling, like striking the crazy-bone,' 'tenseness and tearing,' and formication. Sometimes there are darting feelings 'like the bursting of a bubble,' sometimes a dull, deep pain or ache when the leg is tired. These manifestations often begin as a glowing sensation in the part. They cease generally on sitting or lying down, but may recur in such attitudes on over-stretching or violently twisting the leg. Deep pressure with the hand over the part may bring them on. The patient is always aware of something wrong there on standing or walking. These sensations are felt every day and interfere with his habits of exercise ....

"On inspection it is apparent that the area complained of corresponds strictly to the distribution of the cutaneous filaments of the external cutaneous femoral nerve. . . . On testing with the needle-point the whole area is found to be far less responsive than normal, and towards the lower portion, just above the patella, anaesthesia is complete. A similar condition is demonstrated on the application of various tests, the tip of the finger, pinching, scratching, and slight pressure. There is little difference in sensation in both legs on deep pressure. The whole area appreciates the application of hot water in a diminished degree, and the lower third is wholly insensible to it."

Excellent descriptions of meralgia paraesthetica have been published since by Stookey (1928B), Lee (1936), Ecker and Woltman (1938), and Corlette (1944). One hundred and fifty cases have been seen at the Mayo Clinic, about three in each 10,000 general admissions. The most common etiological factor is an abnormal arrangement of the nerve as it emerges from the fascia under Poupart's ligament just medial to its attachment to the anterior superior spine of the ilium. Here the nerve may be compressed and angulated, so that it is placed under tension as the individual stands and walks. There are, however, numerous other factors which have been well described by Ecker and Woltman and also by Lee. These comprise local obesity, pressure from belt, corset, or truss, retroperitoneal irritation of the nerve as it crosses the iliacus muscle after emerging from the lateral margin of the psoas, and radicular injury within the spinal canal or intervertebral foraminae, by caudal neoplasms, arachnoidal adhesions, protruded discs, arthritic spurs, and other forms of vertebral pathology.

While many cases may subside spontaneously or after correction of local irritative factors, and the majority never cause more than minor complaints, a small proportion demand neurosurgical intervention. Ecker and Woltman (1938) stated that "resection of the nerve is now the standard operation for the condition, and the result usually is completely satisfactory"; Lee advocated a neurolysis with freeing and straightening the course of the nerve if it is found to be angulated. From our own unsatisfactory experience and observations of the poor results of other surgeons, we believe that both neurolysis and neurectomy often fail, as they do in attempts to relieve other forms of neuralgia in partially injured nerves.

This is due at times to the formation of a painful neuroma, but also, in this particular condition, to failure to recognize pathological factors at higher levels. We have recently had the good fortune to diagnose a painful neuroma-in-continuity of the lateral femoral cutaneous nerve, injured in its retroperitoneal portion in the course of a lumbar sympathectomy (Gertrude C., MGH U-806115). Division of the second and third lumbar posterior roots has relieved the painful paraesthesiae in the anterolateral thigh over a period of four months.

We have seen three failures after the standard operation at the level where the nerve emerges from under Poupart's ligament. Two of these neurectomies had been performed at this hospital and the third elsewhere. Continued or recurrent pain in all was undoubtedly due to central lesions; one (Frank di L., MGH U-407107, 55) from arachnoiditis or lumbar disc secondary to trauma, a second (Charles McL., MGH U-334362PH, 63) from retroperitoneal scarring and recurrent malignant disease following resection of the ascending colon, and a third (Mrs. Jacqueline V., MGH U-164891BM, 27) from old trauma and the effects of spinal fusion.

The latter patient was of particular interest, because Dr. Leo Davidoff was eventually forced to perform a spinothalamic tractotomy, after three resections of the nerve at successively higher levels and lumbar laminectomy with lysis of adhesions had failed to relieve her pain. The cordotomy gave complete relief of the neuralgic pain in the lateral thigh, but was followed by a most unusual complication for which she was referred by Dr. Davidoff to one of us. Following this otherwise successful operation the young woman had developed the local radicular pain so often seen after incision of the spinal cord and manipulation of its roots. Instead of spontaneously subsiding, however, it developed into the classical syndrome of Weir Mitchell's causalgia of the forearm and hand. This area became the site of an intense burning hyperpathia with hyperalgesia and trophic changes. She was forced to wrap the arm in cold moist towels and was unable to wash the skin or cut her nails. The only variation from the wartime causalgias described above was the fact that emotional stimuli did not increase the pain. Also it was impossible to relieve the neuralgia by paravertebral procaine block of the sympathetic ganglia, or even of the brachial plexus. We felt that the pathological focus of this unusual disturbance lay within the cord itself. The patient, a woman of great fortitude, agreed to wait for spontaneous remission, which took place gradually during the course of the next five years.

In summary, we believe that neurectomy in meralgia paraesthetica should be undertaken only on the most clearcut indications of local irritation at Poupart's ligament. Most diligent search should be made for central lesions of the nerve or its spinal roots, and Ecker and Woltman's (1938) statement should always be borne in mind—"when the symptoms have lasted less than two years, the chances are two to one that they will disappear spontaneously within another two years."

CHAPTER XIV

FACIAL AND CEPHALIC NEURALGIAS: TRIGEMINAL NEURALGIA (TIC DOULOUREUX, TRIFACIAL NEURALGIA)

A. CLINICAL FEATURES

IT IS PLEASANT TO BEGIN A DISCUSSION of pain in the head or face with a consideration of idiopathic trigeminal neuralgia. In this disorder, nearly as common as intracranial tumour, the patient's life is rendered miserable by his pain, and we possess certain and simple methods of providing relief. Identification of the syndrome depends on ascertaining that:

1) The pain is *paroxysmal*—lasting only seconds to a few minutes and usually of extreme intensity. It is described by the victim as "knife-like stabs," "electric shocks," or "jabs with a red hot poker." In the intervals between these violent experiences there is usually no pain, or at most a mild dull ache.

2) Such devastating outbursts are *provoked by obvious stimuli* to the face. Any touch, a draft of air, movement of the face, as in talking, chewing, yawning, or swallowing, even a movement of any part of the body jarring the face, may suffice to evoke a lancinating attack. Often there is a transitory period of immunity after the brief period of torture during which time the patient can rapidly gulp down a few bites of food before the agonizing response to casual stimuli within the trigeminal area returns. In other severe cases no such respite from the tendency to paroxysms occurs or the individual is too terrified at the prospect of the pain to risk the test of eating, and nutrition suffers. The disorder may be ushered in over a period of years by much milder manifestations of the same type.

3) The pain is *confined to the trigeminal zone*—nearly always on one side. Any spread of the pain to the ear, neck, throat, or posterior half of the scalp should lead one to suspect some other diagnosis. At times some trigeminal branches may extend well beyond the usual domain of the nerve. Penman (1950), for example, had a patient with a painful trigger zone over the mastoid process; after a trigeminal alcohol injection this zone was included in a strip of analgesia 3 cm. wide behind the ear. He cites three other references attesting to radiation well outside the customary trigeminal area.

4) *In any particular paroxysm the pain is referred to only one side of*

the midline. Even in those who develop bilateral trigeminal neuralgia the cycles of pain on the two sides usually occur consecutively rather than concurrently.

5) There is *no hypaesthesia or hypalgesia* upon routine clinical testing with cotton wool or pinprick.* Although the patient's suffering may impel one to forego a careful sensory examination of the painful part of the face, it is advisable to make a gentle effort to determine any zones of partial sensory loss before denervating a portion of the face. By overlooking an area of hypaesthesia one may fail to diagnose a tumour.

If the patient's pain fails to meet any of these five criteria the diagnosis of idiopathic trigeminal neuralgia is unlikely. Other common features are the presence of a special sensitivity in some one small "trigger zone" of the face, stimulus to which the patient scrupulously avoids. The pain usually starts here and radiates to other parts of the face; injection or section of the trigeminal nerve supply to this particular area alone usually stops all of the pain. Thus, if the pain starts at a nostril and radiates up to the ipsilateral eye and forehead only the maxillary division or its infra-orbital branch need be cut. In many instances pain starting at one point tends to radiate along a constant line to another area. These lines of reference of pain do not necessarily correspond to the anatomical course of main trigeminal branches as some authors have contended.

Between attacks patients protect the face by immobility; women often wear delicate woollen shawls. Once an attack begins, though, the face may become contorted (hence the word "tic"); the hand may clutch the painful area; the whole face may redden and the eyes water until the bout subsides. The attacks rarely occur at night unless the patient awakens from other causes. Paroxysms come in cycles, each lasting several weeks or months, with intervals of freedom between during which the patient vainly hopes the disease has disappeared. Unhappily successive cycles tend to be worse and to come more often; spontaneous recovery is rare. The extraction of teeth or retained roots is likely to do no good. The disorder usually comes on in the second half of life, and the younger the patient the more likely is another diagnosis. Barclay (1922), however, reported a case in a boy aged 10 years and Grant has shown us one only nine. Harris' series (1926, p. 158) includes nine patients in the second decade.

---

*Lewy and Grant (1938), however, find that when sensation is tested with calibrated hairs, thorns, or electrical current, one-quarter of their untreated patients have in some areas of the painful zone a reduced number of touch and pain points, and that the points remaining have a higher threshold of excitability.

B. ETIOLOGY

The cause and mechanism of the syndrome remain obscure. Wolff (1948, pp. 551-557) has adduced evidence that a paroxysmal ischaemia of the sensory root, Gasserian ganglion or its peripheral divisions may cause tic douloureux. The suggestion that angiospasm is the basis for the trouble has appeared many times in the literature, but even if this is the case sympathectomy is not likely to stop the pain, although some favourable reports to the contrary (Flothow, 1930; McKechnie, 1933) provide a bit of support for this hypothesis. Foerster (1927A, p. 218) mentions that the redness of the face during an attack of pain argues against this viewpoint. "Sclerosis" within the Gasserian ganglion has been implicated by Frazier (1918) and by Adson (1926); Patrick (1914), on the other hand, thought such changes in the ganglion too indefinite to justify any such conclusion.

Dandy (1934) contended that the disorder must affect the sensory root since he found tumour, basilar aneurysm, or cavernous angioma adjoining the root in 10 per cent and "some affection of the root by an artery" in 31 per cent of 215 cases of trigeminal neuralgia treated by his sub-cerebellar approach. Because he was unable to find any report of a tumour of a peripheral branch or of the Gasserian ganglion accompanied by tic douloureux, he considered compression of the sensory root to be peculiarly likely to produce this syndrome. However, Hamby (1952), Hyslop (1936) and Love and Woltman (1942) have all reported typical trigeminal neuralgia due to external compression of peripheral trigeminal branches, and we have seen one such patient with a carcinoma of the maxillary antrum. In a later report of Dandy's material by Revilla (1947) there were 24 tumours in the posterior fossa in the region of the fifth nerve among 473 patients "diagnosed preoperatively as tic douloureux," and operated upon via the cerebellar approach. However, there was involvement of one or more other cranial nerves in 10 of the 11 neuromas, three of the nine epidermoids, and one of the four meningiomas in this group, so that the diagnosis of idiopathic trigeminal neuralgia in the majority of the 24 is perhaps unjustified. If the incidence of cerebellopontine angle tumour in this disease is 5 per cent as recorded in both of Dandy's series it seems remarkable that more such tumours do not crop up in the late postoperative or post-injection period in patients treated without inspecting the root in the posterior fossa. Hamby's (1943) finding of only four cases of cerebellopontine angle tumour in his series of cases erroneously diagnosed trigeminal neuralgia is more in line with our experience. Pains typical of trigeminal neuralgia may even be evoked by tumours on the contralateral side of the posterior fossa; Parker (1937) and Hamby (1947) have described such cases.

If properly placed, lesions in certain chronic disorders of the nervous system, especially multiple sclerosis, are clearly capable of producing pain indistinguishable from that of the disorder under consideration. Harris (1927, p. 403) reported 23 cases of trigeminal neuralgia associated with chronic spastic paraplegia—he thought the majority of these patients had multiple sclerosis. Parker (1928) collected several cases from the literature and added one of his own in which a plaque of multiple sclerosis was found at necropsy in the pons at the point of entrance of the posterior trigeminal root, on the side affected by pain. Lewy and Grant (1938) placed the lesion more centrally. On the basis of six autopsied cases they suggest that lesions in the thalamus or thalamocortical tract are responsible for the pain and "that major trigeminal neuralgia is a special form of a thalamic syndrome."

C. TREATMENT

1. Temporary Measures

a) Medical treatment:—We have found no sustained relief from inhalations of trichlorethylene or intravenous injections of vitamin B_1 (thiamine chloride), or of vitamin B_{12}.

b) Chemical nerve block:—The cheering feature of this condition is the disappearance of the pain upon denervation of the appropriate trigeminal area. This can be accomplished in the first instance by temporary measures lasting a number of months. Levy and Baudoin (1906) introduced the most important of these, injection of alcohol into the second and third divisions at the foramen rotundum and foramen ovale respectively. F. A. Duncan Alexander (personal communication, 1952) has found that 6 per cent phenol yields less lasting anaesthesia than does alcohol for blocks of these somatic nerves. Many including Cushing (1920A), Jefferson (1931A), Adson (1935B), Grant (1936) and Horrax and Poppen (1935) continue to recommend beginning with manoeuvres such as alcohol injection of the second and third divisions and peripheral neurotomy of the branches of the ophthalmic division. There are three advantages to this tactic:

1) If such a procedure results in temporary anaesthesia and affords relief of pain, then a permanent denervation will afford the same relief. Conversely, if pain continues in the anaesthetic zone after a peripheral procedure on the nerve, then the patient does not have trigeminal neuralgia and a more central attack on the fibres in the posterior root will also fail. This is exemplified by the following case history:

Susan G. (M.G.H. #136569), a 45-year-old spinster, had had an antral sinusitis with an ensuing small area of osteomyelitis above the socket of an

extracted L. upper bicuspid tooth. Surgical treatment of the antrum and jaw had long since cleared up all evidence of residual infection. On examination she complained of continual dull pain in the maxilla with a tender area in the side of the upper jaw. After telling the patient that she did not have trigeminal neuralgia and would probably not have relief following anaesthesia, we injected alcohol into the maxillary nerve in the pterygo-maxillary fossa on 5/10/39. It was followed by complete anaesthesia of the second division, except in the area of the superior alveolar nerve. This was effectively blocked four days later by a second injection. Nevertheless she complained that she had some of her former pain on discharge next day.

When re-examined a week later, second division anaesthesia remained complete, but she continued to suffer from a steady aching pain in the socket of the extracted tooth. She was therefore told that nothing would be gained by retrogasserian neurotomy and advised emphatically never to have the root cut. Unfortunately she paid no attention to this and persuaded a prominent member of our profession to carry this out. When next seen she had total anaesthesia, a complicating abducens paralysis, but no alleviation of her neuralgia. She has continued to suffer over the intervening years and has failed to respond following stellate block with procaine, infraorbital neurectomy, temporal arteriectomy, and section of the descending trigeminal tract in the medulla performed by a galaxy of distinguished neurosurgeons.

2) There is a variable degree of constant unpleasant sensation in the face following trigeminal posterior rhizotomy. Only the patient can decide whether he prefers paraesthesias to the original paroxysms of pain. If the continuous sense of swelling, itching, burning, or other annoying sensation in the face, which a few folks have, proves unexpectedly troublesome, this will all disappear with regeneration of the nerve. The duration of block following procaine is too short for the patient to assess his tolerance to the paraesthesias. Although even preliminary alcohol block cannot always be counted upon to exclude the risk of severe lasting paraesthesias, these can be so disturbing that no measure should be left untried to avoid them. This is brought out by the following case history:

A middle-aged man had had a primary neurectomy of the retrogasserian root for classical trigeminal neuralgia. The operation had been performed in one of the leading neurosurgical clinics of this country, where the surgeon-in-chief felt that preliminary alcohol injection was a waste of time. The severe intermittent tic was effectively relieved, but he developed a constant pain in the anaesthetic side of his tongue which felt as though it were so swollen that it would burst. After suffering for several years he came to this hospital 15 years ago. In desperation, one of us cut his lingual nerve. He was not benefited and was told that no other treatment was known that could help him. A short time after discharge he committed suicide.

Even if the patient tolerates his troublesome sensations following effec-

tive alcohol injection, this unfortunately is not an absolute guarantee against the development of anaesthesia dolorosa subsequent to trigeminal rhizotomy. In fact Olivecrona (1939) thinks that successful alcohol injections do not help in determining whether or not section of the root will be well tolerated. Several of his patients with this complication have had prior to rhizotomy one or more injections of alcohol, following which their complaints about the anaesthesia were not unusual, and gave no intimation that painful paraesthesias would supervene after division of the root. We have seen only one such patient, (B.F., M.G.H. #770106) who had numbness of his cheek and upper lip following each of three successful second division alcohol injections carried out by Dr. S. Lowis. Pain was relieved for 16, 12 and 10 months respectively after each injection and there were no troublesome paraesthesias, but, after total trigeminal rhizotomy, relentless aching pain developed around the eye and has persisted for the 18 months since; the patient says it is worse than the original neuralgia. Perhaps the paraesthesias would not have appeared had the rhizotomy, like the alcohol injections, left intact the orbital innervation.

3) In patients weakened by inability to eat, injection of the nerve will permit normal food intake and decrease the operative risk. In those likely to die soon, completion of the life span without operation may occur.

More recently many surgeons have considered alcohol injection unnecessary, e.g., Peet and Echols (1946, p. 253) and Ray cited by Wolff (1948, p. 557). The pain of injections which must be carried out under local anaesthesia and the frequency of failure to block the nerve have been cited as reasons for abandoning this preliminary to operation. In Chapter V we describe our methods for decreasing the pain and increasing the accuracy of needle placement which lead us to continue it.

The duration of relief of pain following alcohol injection of the mandibular division averaged a little over 16 months in Grant's (1936) series and 14.3 months in the group of Horrax and Poppen (1935). By rotating the bevel of the needle upward once analgesia of the mandibular division was secured and injecting a total of 2 to 4 cc. of alcohol, we have increased the length of nerve destroyed, have perhaps destroyed some ganglion cells, and have prolonged the average duration of relief of pain to 30 months in one series (Sweet, 1950). Grant's patients, with injections of the second division in the pterygopalatine fossa were relieved for 14+ months and those with injection of the supraorbital nerve for 11+ months. We suggest injection in the infra-orbital foramen only when one has failed to infiltrate the entire second division in the pterygopalatine fossa. In our experience return of the paroxysms of pain has been correlated with fading of the analgesia to hypalgesia or normal sensation in at least a portion of the previously numbed area. Table XXII, prepared by Dr. Louis Bakay, sum-

TABLE XXII
TRIGEMINAL NEURALGIA
EFFECTIVENESS OF SUCCESSIVE ALCOHOL INJECTIONS

		Number of Cases	*Relief > 2 Weeks*	*Average duration when relief is > 2 weeks*
3rd division at foramen ovale	1st injection	64	73%	18 months
	2nd injection	26	58%	12 months
	3rd injection	8	38%	8 months
	4th injection	1	0%	
2nd division at foramen rotundum	1st injection	73	77%	11 months
	2nd injection	33	67%	7 months
	3rd injection	11	55%	8 months
	4th injection	5	40%	8 months

marizes a series of alcohol injections performed at the Massachusetts General Hospital largely by the resident staff. This reveals that *there is a pronounced tendency for the percentage of failures to increase and the duration of relief to diminish with each successive injection. We point this out to our patients and, following the first successful injection, usually urge operation when severe pain recurs.*

2. Permanent Measures

a) Retrogasserian rhizotomy in middle fossa

i) Temporal extradural route:—Division of a part or all of the posterior root of the trigeminal nerve has come to be the standard operation for producing permanent anaesthesia in the zone of the trigeminal nerve. Horsley, Taylor, and Colman (1891C) recorded the first such attempt, but Horsley's transtentorial approach ended fatally. It remained for Spiller and Frazier (1901) to publish the first successful result by the now classical infratemporal approach to the root in the middle cranial fossa. Cushing (1920B) succeeded in chalking up a spectacular record of successful removals of some or all of the Gasserian ganglion, an operation originally carried out by Hartley (1892) and Krause (1893B), but this more difficult procedure accomplishes no more than posterior rhizotomy and has been abandoned. Adson (1926) and Meirowsky and Pipito (1943) have given accounts of the evolution of efforts at surgical treatment.

Frazier later introduced two important improvements in his operations: 1) subtotal section of the sensory root conserving the ophthalmic fibres in 1915, and 2) preservation of the motor root in 1918. In the report (1925B) of his experience with subtotal division of the sensory root he presented evidence that if anaesthesia is produced throughout the zone in which the paroxysms start the patient will be freed of all pain. In order to diminish

tive alcohol injection, this unfortunately is not an absolute guarantee against the development of anaesthesia dolorosa subsequent to trigeminal rhizotomy. In fact Olivecrona (1939) thinks that successful alcohol injections do not help in determining whether or not section of the root will be well tolerated. Several of his patients with this complication have had prior to rhizotomy one or more injections of alcohol, following which their complaints about the anaesthesia were not unusual, and gave no intimation that painful paraesthesias would supervene after division of the root. We have seen only one such patient, (B.F., M.G.H. #770106) who had numbness of his cheek and upper lip following each of three successful second division alcohol injections carried out by Dr. S. Lowis. Pain was relieved for 16, 12 and 10 months respectively after each injection and there were no troublesome paraesthesias, but, after total trigeminal rhizotomy, relentless aching pain developed around the eye and has persisted for the 18 months since; the patient says it is worse than the original neuralgia. Perhaps the paraesthesias would not have appeared had the rhizotomy, like the alcohol injections, left intact the orbital innervation.

3) In patients weakened by inability to eat, injection of the nerve will permit normal food intake and decrease the operative risk. In those likely to die soon, completion of the life span without operation may occur.

More recently many surgeons have considered alcohol injection unnecessary, e.g., Peet and Echols (1946, p. 253) and Ray cited by Wolff (1948, p. 557). The pain of injections which must be carried out under local anaesthesia and the frequency of failure to block the nerve have been cited as reasons for abandoning this preliminary to operation. In Chapter V we describe our methods for decreasing the pain and increasing the accuracy of needle placement which lead us to continue it.

The duration of relief of pain following alcohol injection of the mandibular division averaged a little over 16 months in Grant's (1936) series and 14.3 months in the group of Horrax and Poppen (1935). By rotating the bevel of the needle upward once analgesia of the mandibular division was secured and injecting a total of 2 to 4 cc. of alcohol, we have increased the length of nerve destroyed, have perhaps destroyed some ganglion cells, and have prolonged the average duration of relief of pain to 30 months in one series (Sweet, 1950). Grant's patients, with injections of the second division in the pterygopalatine fossa were relieved for 14+ months and those with injection of the supraorbital nerve for 11+ months. We suggest injection in the infra-orbital foramen only when one has failed to infiltrate the entire second division in the pterygopalatine fossa. In our experience return of the paroxysms of pain has been correlated with fading of the analgesia to hypalgesia or normal sensation in at least a portion of the previously numbed area. Table XXII, prepared by Dr. Louis Bakay, sum-

freedom of pain (9/1/51), despite the return of appreciation of pinprick to the left forehead and preservation of corneal sensation.

A similar case was reported by Hyndman (1941).

Preservation of the motor root was of particular value in the days when the only satisfactory permanent cure for the disorder consisted of an operation directed against the ganglion or posterior root in the middle cranial fossa. In rare cases pain appears on the other side of the face and Frazier in 1926 first operated successfully on such a patient sparing her second and only intact motor root. However, a paralyzed group of muscles of mastication on one side produces no significant physiologic disturbance, and the atrophy of the temporal and masseter muscles constitutes only a slight cosmetic defect. The question has been repeatedly raised as to whether any afferent fibres travel with the motor root; no decisive answer has been given to this, but Grant (1938) has pointed out that preservation of the motor root does not increase the frequency of postoperative paraesthesias.

The mortality and complications of the Frazier type of operation as well as an indication of the type of patient with this disease are set out in Table XXIII. By 1928 Frazier was able to report a mortality of only 0.37 per cent in his last 269 consecutive operations. These major publications, the work of several early neurosurgical masters with long term follow-ups, appeared 10-25 years ago. We include the data assembled by Dr. Bakay from our own hospital for the 11 year period 1937 to 1947, during which time a substantial number of these operations were carried out by resident staff members who were in their first year as neurosurgical operators. The technical steps and safeguards of retrogasserian neurotomy have been described so well by the pioneer neurosurgeons of the past generation that the mortality and complications among this relatively inexperienced group compare favourably with many of the earlier figures in all categories except the higher percentage of recurrences. The only fault we can find with our late results is ascribable to too limited denervation, an excusable failing in a situation where reoperation is so easy, or to cutting the rootlets too close to the ganglion

Of the various complications it has long been surmised that the infrequent facial weakness or paralysis which typically appears only some hours or days postoperatively is due to traction on the greater superficial petrosal nerve or haemorrhage into its sheath with consequent trauma to the geniculate ganglion, from which the nerve arises. Subsequent compression of the main motor fibres of the facial nerve in the facial canal then occurs. Gardner, Stowell and Dutlinger (1947) have virtually proven this hypothesis by provoking a high incidence of temporary facial paralysis when they deliberately elevated the greater superficial petrosal nerve on

the area of postoperative numbness he at times cut only those rootlets which seemed to be going to the one of the three major divisions of the nerve in whose area the pain began. Since attacks rarely start in the first division this meant that the innervation of the cornea can be preserved in the great majority of patients and the complication of corneal ulceration from an insensitive cornea avoided. The disorder is not likely to spread to the areas with intact innervation, as shown by Grant (1938). There was later spread of major pain into innervated zones in only 44 (7.5 per cent) of 590 patients who had undergone deliberate partial section, whereas pain reappeared seven times, i.e., in 2 per cent of 259 cases in whom division was presumably complete. In this latter connection we consider it important to divide the rootlets well behind the ganglion in order to be posterior to any aberrant cell bodies which may send regenerating fibres anteriorly. Perhaps we have not done this as conscientiously as we should have in the past, because the recurrence rate at the Massachusetts General Hospital has been higher—25 per cent of 123 patients who had subtotal sensory root section from 1937 to 1947, and 7 per cent of 126 persons who had a presumably total sensory root section during the same 11 year period (L. Bakay, 1950, personal communication). Guillaume (1947), however, thinks that a differential root section should be carried out immediately behind the ganglion. He points out that there is an incomplete rotation and mixing of the fibres from the three divisions as they pass toward the pons; he also considers this an additional reason for carrying out the operation in the middle rather than the posterior fossa.

There are a few exceptions to the rule that denervation of the division in which the pain begins will give relief. An example of this is given by the following case record:

Patient Y.Y. (M.G.H. #495084) developed paroxysms of pain in the left cheek and upper lip in 1944. Dr. Kurt Thoma removed the infraorbital nerve on 6/29/45 and the pain was gone for 21 months. It recurred in the left forehead but not in the area of the second division. No pain was felt anywhere below the eyebrow, but the outbursts were likely to be provoked by touch or pressure in the region of the alveolar process of the left maxilla or the left hard palate. This fact, plus the earlier relief of pain by infraorbital neurectomy, made one hope that it would be possible to save the ophthalmic division's innervation of the cornea and still stop the pain. To test out this possibility anaesthesia of the forehead was produced by avulsion of the supratrochlear, frontal and supraorbital nerves and twigs from the lachrymal branches of the ophthalmic division on 6/4/47, but the stabs of pain in the forehead continued unabated, occurring spontaneously or whenever the upper gum was touched. Differential retrogasserian neurotomy of all but the uppermost two rootlets on 6/13/47 has been followed by complete

a hook and then divided it. When they cut this nerve as it lay in its groove the frequency of facial paralysis was reduced.

Another significant complication of trigeminal rhizotomy, keratitis, often followed by corneal scarring and some degree of blindness, was reduced from an incidence of 16 per cent in 359 cases of complete root section to 4 per cent in 590 cases in which some corneal sensation was presumably preserved (Grant, 1938). No eyes were lost in the latter group, whereas 10 per cent of the keratitic eyes were lost in the earlier group. Division of the greater superficial petrosal nerve by reducing lacrimation may predispose to a milder form of keratitis, as illustrated by two patients of Gardner, Stowell and Dutlinger—a further reason for avoiding injury to this nerve in the course of trigeminal rhizotomy. Rowbotham (1939) has shown that, although lacrimation may be reduced, it is not abolished by cutting the greater superficial petrosal nerve. In one of our cases, where the amount of tear secretion was tested by Dr. E. B. Dunphy, there was no detectable dryness of the conjunctiva, but reflex secretion of tears (on smelling ammonia) was abolished on the side of petrosal neurectomy.

A number of other complications may be discussed briefly. Ocular palsies occur infrequently and are rarely permanent. Since the operation is carried out extradurally, wound infections almost never lead to meningitis, and troublesome cerebral oedema rarely develops. A transitory aphasia occurred once in our series. An extradural haematoma can be a most dangerous complication, if a branch of the middle meningeal artery breaks loose. This eventuality must always be guarded against by ordering the nurses to observe the level of consciousness, the development of Jacksonian seizures or of hemiparesis during recovery from anaesthesia and during the first night after operation. On any suspicion of cerebral compression the incision should be reopened. If promptly diagnosed and evacuated such a clot will do no harm, but if operation is postponed until deep coma supervenes, the victim is unlikely to recover. Since many of the operations are done in old people, a variety of forms of cerebral vascular accidents may occur, but happily do so rarely. Complaint of unilateral hearing loss on the side of the operation has been correlated by Gardner and Babbitt (1929) with the entrance of blood into the tympanic membrane or even into the middle ear. This disturbance is only a temporary one. After 160 operations in which postoperative otologic studies were carried out, 13 of their patients showed such haemorrhage, but subjective hearing loss was present in only three. Vesicles of herpes simplex appear on one or both lips commonly after operation but are of no consequence.

The principal complication of trigeminal rhizotomy which has led to efforts to improve the operation is seen in a small group of patients whose continuous paraesthesias in the anaesthetic zone make them as unhappy as

TABLE XXIII

TRIGEMINAL NEURALGIA–POSTERIOR RHIZOTOMY IN MIDDLE FOSSA

Author	*Total No. of Patients*	*% Female*	*Over Age 50*	*Bilat Involvement*	*Op Mortality*	*Keratitis or Iritis*	*Transitory Facial Paralysis or Paresis < Year*	*Paralysis Facial > Year*	*Serious Post-op Paraesthesia*	*Ocular Palsy*	*Recurrence*
Adson 1926	387	47%	71%	2%		3.4%	7.2%			0.5%	
Craig 1941	434			2%	1.9%	1 1%					3%
Sachs 1935	182	52%	77%		2.3%	7.7%	9.9%				
Grant 1938	925			1.8%	1.30%	9%	3 4%	.65%	3.4%	1.1%	5.4%
Bakay MGH Series 1937-1947	250	61%	78%	0.8%	1.6%	4.4%	4.0%	1.6%		1.6%	13.6%
Guidetti 1950, Olivecrona's Clinic	515		20% over 60		.77%				3.1%		8 3%
Peet and chneider 952	544	57%	74%	5.9%	1.6%	15.1%	0.5%	?		.4%	14.1%

this thought he has opened the dural sheath of the root or dura propria from the back of the Gasserian ganglion posteriorly over the petrosal ridge through the superior petrosal sinus or even on through the edge of the tentorium. Ten such patients were all free of their postoperative pain an average of four months and a maximum of eight months after operation at the writing of his first report in February 1952. By February 1953 he had done 40 of these operations for trigeminal neuralgia with two major and three minor recurrences. In one of the recurrences his original operation had been carried back through the petrosal sinus. At a second procedure he carried the incision further back through the free edge of the tentorium, again securing relief. When incising at the tentorial edge one must take care to avoid the trochlear nerve, injury to which has caused several permanent and temporary paralyses in the series of Taarnhøj.

Beginning in the summer of 1951, Pudenz and Shelden (1952) began to treat trigeminal neuralgia by enlarging the foramen rotundum and foramen ovale to two or three times their original size, using dental burrs. They then injected saline into the second and third divisions and cut the nerve sheath. They have done this "decompression and neurolysis of maxillary and mandibular nerves" on six patients. Of these, two have had recurrence of pain at nine months and one year respectively. They mention that the nerves did not appear to be compressed at their foramina of exit in any of their patients. The tentative proponents of both operations emphasize the preliminary character of their reports. When many posterior rootlets are divided the space for the remainder after degeneration of those cut should surely be ample if compression is in fact a problem. Yet we have seen recurrences when the area of any remaining superficial sensibility is only 1 cm. in diameter, so that we are particularly skeptical of the procedure of Taarnhøj. In addition there is a well known tendency for trigeminal neuralgia to undergo relatively long remission after such manoeuvres as procaine injection into the peripheral branches. Rowe (1952) has even mentioned the patient of another surgeon who had relief for two years after trigeminal rhizotomy on the wrong side! Hence we suggest awaiting more definite reports before anyone else tries either of these procedures.

A flashback to the last century may be pertinent at this point. In 1886 Fowler collected a total of 17 case reports from the literature describing treatment of facial neuralgia by ligation of the common carotid artery. Relief lasted more than three years in four instances, and for from one to three years in three; two cases were reported cured although the duration of relief was not given; relief lasting less than one year occurred in four more. These results along with recent glowing reports on the value of certain vitamins intravenously indicate that trigeminal neuralgia has for 65 years been a fruitful field in which to describe new and successful ther-

they were before operation. Such people say that the sensation of a burning deep ache or of excessive itching, tingling or formication, which is constantly present, could be tolerated a few hours a day, but its unremitting character may make them desperate. Of Grant's 925 patients 13.8 per cent complained of paraesthesias and these were severe in 3.4 per cent. Nearly half of the latter appear within six weeks of operation and the remainder within the first year. Mixter and White (1931) reported relief of this symptom in one case following cervicothoracic sympathetic ganglionectomy, but this improvement did not last and in the 15 of Grant's group who had *various operations directed against the sympathetic supply to the face* the results were "very indifferent." Olivecrona (1939) also failed to relieve this complication either: 1) by completing a partial trigeminal rhizotomy; 2) by removal of the inferior cervical and upper two thoracic sympathetic ganglia; 3) by stripping of the carotid artery, or 4) by bulbar trigeminal tractotomy. For the treatment of this type of "anaesthesia dolorosa" by frontal lobotomy see Chapter X. A distressing tendency to scratch the itching paraesthetic skin, which is also anaesthetic, may result in the patient tearing away a portion of the face such as the nostril. We have seen one such patient in our series at the Massachusetts General Hospital. Peet (1940) reported two others—an incidence of only .2 per cent in his series of 1000 trigeminal rhizotomies.

For the typical case of trigeminal pain the temporal extradural approach and section of the retrogasserian sensory root is the safest and best procedure.

ii) Temporal intradural route:—A few surgeons open the dura and elevate the temporal lobe, then cut through the dura again over and just behind Meckel's cave to divide the root as it lies in its groove near the tip of the petrous bone, or cut the tentorium and divide the root in the posterior fossa. Since this procedure exposes the temporal lobe to direct retraction it has been taken up by only a few neurosurgeons. Portugal (1946) reports 118 cases handled in this way. Wilkins (personal communication, 1953) has favoured this approach because it obviates any traction on the greater superficial petrosal nerve and has never led to complicating facial weakness. *We recommend it only as a last expedient when an extremely adherent dura or some other anatomical abnormality makes extradural exposure of the root impossible.*

b) Decompression of trigeminal branches, ganglion or root:—Brief mention may be made of two operations now undergoing therapeutic trial. Taarnhøj (1952) *has hypothecated that slight compression of the posterior* rootlets may occur, especially as they pass over "the upper sharp margin of the petrous bone" between the middle and posterior fossae. In line with

Instead of injecting alcohol through a needle Kirschner (1931) proposed electrocoagulation of the ganglion by means of a needle insulated except at its tip. By 1933 he had also developed a special frame and aiming apparatus which was attached to the head just prior to taking of a basilar roentgenogram of the skull. In 1936 he reported that this procedure had enabled him to introduce the needle through the foramen ovale at the first thrust in 90 of his last 100 cases. Of 250 patients with trigeminal neuralgia treated by electrocoagulation he failed to give relief to only 4 per cent. Recurrence had already taken place in 25 per cent of his cases at the time of his relatively early report, but he considered this no disadvantage, stating that recoagulation was so easy to do. He had perfected the procedure to the point of doing seven patients in 90 minutes. He illustrates one pathological specimen obtained after subsequent operation in which a rim of apparently viable ganglion cells completely surrounds the central, partially empty, necrotic area. If this is typical one would anticipate a recurrence in most of the cases as time passes. In order to destroy the remaining rim of cells Kirschner followed his electrocoagulation for a time by injection of alcohol, but later abandoned this. The vicissitudes of World War II appear to have prevented long term follow-ups of patients treated by electrocoagulation.

This method with the special anthropometric apparatus developed by Kirschner has been taken up by a number of European surgeons. Others have employed electrocoagulation, but have used less elaborate methods for inserting the needle tip into the region of the ganglion. We summarize the results in some of the reported series in Table XXIV. As in other forms of surgical treatment in this disorder, useful relief may follow incomplete destruction of the afferent pathways. Thus in one of Kubanyi's patients, who had had an extremely severe neuralgia involving all three divisions of the nerve, there was, following electrocoagulation of the ganglion, complete freedom from pain for the remaining 14 months of life. Post-mortem following this man's accidental death showed that only about half of the ganglion had been destroyed.

Oddsson (1944) has given a comparative judgment on the results of the Kirschner method in 86 patients from the vantage point of the excellent neurosurgical service of Busch in Copenhagen. Although there were no deaths, there were four cases of neuroparalytic keratitis and a recurrence rate of 30 per cent. He concluded that most patients with major trigeminal neuralgia should be treated by subtemporal rhizotomy, but that in patients not likely to stand this operation the Kirschner procedure should be considered in those with pains affecting the third division. It was the mandibular neuralgias which yielded most often to primary electrocoagulation and which showed the fewest recurrences

apy! *Long follow-ups of substantial numbers of cases are clearly prerequisite to even a tentative conclusion.*

c) Alcohol *injection or* electrocoagulation of the Gasserian ganglion:—Harris (1912) first described a lateral approach for alcohol injection of the Gasserian ganglion through the foramen ovale, reporting seven cases. Härtel (1914) followed with his description of reaching the foramen by inserting the needle between the maxilla and ramus of the mandible. Both of these capable performers have remained exponents of infiltrating the ganglion and each has accumulated an impressive series of results (Härtel, 1935; Harris 1937 and 1940A). Of Härtel's 137 cases treated since 1912 he was unable to puncture the foramen ovale in only four. The remaining 133 secured initial relief. He followed up 103 of them and learned that 68 per cent maintained total anaesthesia, with enduring relief of pain in nearly all of this group. Of the 32 per cent whose anaesthesia was only partial, the pain had recurred in all but those whose injection had been done less than two years previously. In Harris' much larger series he followed up the 765 of his patients in whom the injection yielded initially "good anaesthesia with relief of pain." Of the 457 patients about whom he could obtain data 69 per cent had had no recurrence of pain for three or more years—a percentage of maintained success almost exactly the same as Hartel's.

As Harris himself was one of the first to emphasize, the alcohol may spread into the cerebrospinal fluid with serious palsies of other cranial nerves, or the cavernous sinus or carotid artery may be punctured with an occasional fatality. Harris avoided such sequelae by passing his needle point intracranially no more than 6-7 mm. "after touching the lips of the foramen ovale" (1926, p. 212). However, the bulk of the ganglion lies further from the foramen ovale than this, and one has to depend on chance that the alcohol will spread to destroy the desired portion. Harris also pointed out the peculiar tendency of the alcohol to produce anaesthesia in the first division before affecting the second. This makes it likely that corneal anaesthesia (with possible subsequent keratitis) will occur early during the diffusion of the alcohol, even though the second division remains unaffected. Harris remarked also that "in many cases the first division will remain permanently anaesthetic, while the second division recovers a considerable amount of sensation." In an effort to increase the accuracy of the needle placement and to insert the point deeper intracranially into precisely that portion of the ganglion one wishes to destroy, several techniques using radiographic control have been evolved. An excellent summary and criticism of previous methods together with a reasonably simple original procedure has recently been proposed by Penman (1949)—see Chapter V.

From our experiences with electrocoagulation for making specific lesions intracranially (see pp. 226-228), we wonder if the relatively crude control of the coagulating current may not result in occasional extension of the lesion to an undesirable degree, even if the electrode is placed correctly. The published reports reveal difference of opinion and uncertainty as to how much and what type of current should be used. If the proponents of the method perfect it so that they can: 1) consistently destroy the second and third divisions while saving the first and other nearby structures; 2) lower their rate of recurrence and 3) keep the mortality nearly zero, many more surgeons will perforce take it up. As far as we know no one has quite demonstrated this degree of skill. As with alcohol injection avoidance of denervation of the cornea seems the major unsolved problem. *We recommend that these methods of destroying the ganglion be reserved exclusively for patients in whom surgical exposure is too hazardous a procedure.*

d) Trigeminal rhizotomy in the posterior fossa:—Dandy found it easy to divide the fifth nerve's sensory root in the posterior fossa, and stated at one time (1932) that he had done 150 such operations without a death or undesirable operative sequela. He never published his total experience with this procedure, however. Since a technical error at the origin of the nerve in the posterior fossa or the development of meningitis may lead to a fatality, few neurosurgeons now use this operation routinely in tic douloureux. Walker (1953) is most enthusiastic about this, however, and has done about 350 patients with the excellent record of only one postoperative fatality on the twenty-second day in a patient who was ambulatory, but wished to die and refused to eat. If the first division is involved, he now divides half or more of the cephalic portion of the root without loss of corneal reflex. When the second and third divisions are affected he divides the caudal part of the root. In either case only a diffuse hypalgesia of varying degree is produced in all three divisions. He always preserved the motor root and none of his patients had had severe paraesthesias. He does not have precise data on his recurrence rate; it is undoubtedly high. This approach is also a valuable one in certain other circumstances, such as extensive malignant disease of the face and throat, and suspicion of neoplasm in the cerebellopontine angle. In Chapter VII we give a detailed consideration of the relative merits of the subtemporal as contrasted with the cerebellar approach to the nerve.

The experience in Olivecrona's clinic (Guidetti, 1950) has included 145 patients. Fractional root sections were done which produced but little loss of tactile (and presumably of pain) sensation in the face. Correspondingly there was a high rate of recurrence of the trigeminal pain (17.9 per cent) with an inconsequential degree of facial paraesthesia, "very

TABLE XXIV

SUMMARY OF REPORTED CASES OF ELECTROCOAGULATION OF GASSERIAN GANGLION

Author		*No of Cases*	*Early Relief*	*Recurrence*	*Complications*	*Deaths*	*Other Data of Interest*
Kirschner	1933	250	96%	25% (early)			
Cassa and Grinda	1946	100+				0	
Philippides	1947	150+				0	
Lemoyne	1946				Keratitis 15% (severe 2 3%)		
Kubanyi	1946	460		28% of 301 patients	Hemiplegias followed by death - 2 Keratitis 13 Permanent corneal opacities 8 Loss of eye 2		301 cases followed up to 6 yrs. Coagulation repeated: 2 x in 75 3 x in 85 4 x in 12
Zenker (Kirschner's clinic)	1938	500 circa				1	
Bauer	1944	700+			"No severe persistent damage"	0	
Oddsson	1944	86	30%		Keratitis 1 cases	0	

side of the incision often occurred, and might persist for over a year following the operation at the level suggested by Sjöqvist. They pointed out that the restiform body covers the descending trigeminal tract above the level of the obex, but that 4-5 mm. below the obex the tract is nearly at the surface of the bulb, covered only by external arcuate and dorsal spinocerebellar fibres. Accordingly, they recommended making the tractotomy incision 4-5 mm. below instead of 8-10 mm. above the obex. In many patients transection of the tract at this lower level will still produce a total trigeminal analgesia. Raney, Raney and Hunter (1950) even state that they are satisfied with the degree of analgesia obtained by section of the tract slightly rostral to the anterior rootlet of the first cervical nerve. Protracted severe ipsilateral ataxia and lateropulsion have not been reported when the incision has been made below the obex.

Paralysis of the recurrent laryngeal nerve may also occur when an incision is made opposite the open part of the medulla. In Sjöqvist's first nine cases this type of paresis occurred four times, and in 30 cases of unilateral trigeminal neuralgia in which Olivecrona (1942) made the incision 2-8 mm. above the obex, the vocal cord was paralyzed on the side of the incision in eight cases and remained so several months after operation in a number of them. In order to avoid these complications both Swedish surgeons have recommended lowering the level of incision.

Jimenez Gonzalez (1944) has drawn attention to the value of recognizing the tuberculum cinereum, that bump on the surface of the medulla immediately beneath which lies the descending trigeminal tract. It lies lateral to the nuclei of fasciculi gracilis and cuneatus. The rostrocaudal level at which it is most marked is apparently variable, but this is said generally to be near the level of the obex. Once this has been identified, Sjöqvist is under the impression that an incision 2-2.5 mm. deep suffices to divide the tract.

ii) Operative mortality:—In general the required incisions into the medulla oblongata have been remarkably well tolerated by patients whose pain was not due to neoplasms of the head or neck. Of a total of 369 operations reported by authors in publications citing more than 10 cases, there were only nine deaths—or an operative mortality of 2.4 per cent. An especially instructive case has been described by Falconer; a patient who had done well for four-and-a-half days after operation suddenly went into coma and died in a few hours. Post-mortem revealed not the "apoplectic stroke" expected, but at the operative site a large extradural clot the removal of which "would probably have saved her life." Olivecrona's two operative deaths were also due to clots in the posterior fossa. The tractotomy is substantially more hazardous when done for pain associated with neoplastic

slight" in only eight patients. The mortality rate of 3.4 per cent now limits their use of the operation chiefly to patients in whom they suspect a space-taking lesion in the angle.

We subscribe to the opinion expressed above, that the posterior approach for section of the sensory root in trigeminal neuralgia should be reserved for cases where it is desirable to explore the cerebellopontine angle.

e) **Bulbar trigeminal tractotomy**

i) Development of the operation:—The descending or spinal tract of the trigeminal nerve extends from the point of entry of the trigeminal rootlets in the upper pons, down through the full length of the medulla oblongata, into the upper cervical cord. Sjöqvist (1938 A and B) was the first to demonstrate that incisions into this tract in the upper bulb would produce loss of pain sensation in the trigeminal area in man. He stated that Hun (1897) had described a patient with complete analgesia but preservation of touch on one entire side of the face, associated at post-mortem with a softening 7-8 mm. long dorsal to the middle portion of the inferior olive, which was caused by a thrombosis of the arterial supply. This suggested that all of the pain fibres descend to this low level in the bulb before terminating at the cells of the nucleus of the spinal tract. Accordingly he made his incision (trigeminal tractotomy as he has called it) into the tract 8-10 mm. rostral to the inferior end of the fourth ventricle, obtaining hypalgesia or analgesia in at least some portion of the trigeminal zone in seven of his first nine patients. In only one of these was it possible to be certain that the tractotomy had produced analgesia throughout the trigeminal area of the face. In this patient deep pressure pain on the frontal bone and maxilla was also eliminated. In all of these patients zones deprived of pain and/or temperature sensation by tractotomy showed preservation of much touch sensation. Walker (1939) and Grant and Weinberger (1941B) were the first to point out that a slight depression of tactile acuity can be shown with von Frey hairs, but this degree of deficit appears to have no clinical significance. Possible advantages of the operation led to its widespread trial. The intactness of touch throughout the face made one hope that the disagreeable paraesthesias and numbness occasionally seen after trigeminal rhizotomy would not occur. Further, since the greater superficial petrosal fibres subserving lachrymal secretion cannot be damaged, it was hoped that the incidence of keratitis would be reduced (Rowbotham, 1938). A paralysis of the masticator or facial muscles as a sequel is also most unlikely.

However, Grant and Weinberger (1941B) soon drew attention to a major disadvantage of incision opposite the open part of the medulla. They found that clumsiness in the hand and fingers and staggering toward the

disease. Of 42 of these we find reported, death occurred in 13. See Table XXV.

iii) Advantages of the operation:—Of the advantages expected from the intramedullary operation, in contrast with section of the root, freedom from numbness and paraesthesias has not been fully realized. Sjöqvist himself (1938A, p. 94) pointed out that in patients who have some trigeminal sensory loss following occlusion of the posterior inferior cerebellar artery, disagreeable facial numbness may be a complaint long after the initial ictus.

TABLE XXV

MORTALITY FOLLOWING BULBAR TRIGEMINAL TRACTOTOMY

Author	*Neuralgias* Deaths		*Total Cases*	*Tumours* Deaths		*Total Cases*
Grant and Weinberger, 1941A.	0	in	6	2	in	11
Olivecrona, 1947.	0	in	13 (migraine)			
Guidetti, 1950 (Olivecrona's cases).	2	in	124			
Sjoqvist, 1948	0	in	23	1	in	4
Hamby, Shinners and Marsh, 1948.	2	in	35	6	in	13
Falconer, 1949.	1	in	20			
LeBeau and Daum, 1950.	2	in	30			
Raney, Raney and Hunter, 1950.	2	in	59			
McKenzie, 1953.	0	in	41			
Our own series.	0	in	18	4	in	14
	9	of	369	13	of	42
	(2.4 per cent)			(31 per cent)		

Spontaneous severe paraesthesias merging into definite pain have been described by others, notably: Wallenburg (1896), Hun (1897), Wilson (1909), Harris (1921), Spiller (1923, Case 2), Thompson (1929, Cases 1 and 3), Winther (1939) and Russel and Stavraky (1934, Case 2).

One might expect that the relatively tiny lesion of a bulbar surgical incision would be less irritant than an extensive softening, and that postoperative paraesthesias would be less of a problem than the postictal phenomena reported. The most encouraging reports on postoperative sensations in the denervated area after tractotomy are those of Olivecrona (1947A and B), who states categorically that in his 101 cases operated upon in this way for trigeminal neuralgia there was not one with paraesthesia or pain (anaesthesia dolorosa). Only one of his 13 cases of migraine had paraesthesias postoperatively. LeBeau, Daum and Forjaz (1948) also found that annoying paraesthesias practically never occurred in their 20 cases. The tractotomy slightly above the cervico-medullary junction to a depth of 4-5 mm. performed by Raney *et al.* (1950) in 59 cases likewise "eliminated the distressing sequelae of sensory root section." This deep caudal incision should transect the nucleus completely as well as the de-

scending tract of the nerve. Sjöqvist (1949) noted only mild paraesthesias in four of his 26 cases. Grant (1948) states that two of the six patients with trigeminal neuralgia on whom he did this operation "complained of paraesthesias" later. Falconer (1949) with a personal experience of 20 cases states that "all patients . . . sometimes only after they had been questioned specifically, reported that they still experience some unpleasant sensations in the analgesic area, particularly in the form of pins-and-needles, tingling pains or itching sensations." None of his patients seemed upset by these paraesthesias. Hamby, Shinners and Marsh (1948) commented on "dysaesthesias" of the face in 12 of 28 patients; seven of the 12 had residual neuralgic type of pain, the other five did not. "In none of the 12 patients did the dysaesthesias have the obsessive quality sometimes observed after trigeminal rhizotomy."

In our experience with trigeminal tractotomy, two patients have complained for years of almost intolerable facial paraesthesias referred largely around the eye, but elsewhere in the face as well. Both have maintained complete trigeminal analgesia to pinprick. The cutting of the so-called trigeminal descending tract was performed for geniculate neuralgia in the case of William T. (Manchester Royal Infirmary) and was also included deliberately incidental to transecting the contralateral pain pathway in the bulb in a case of painful phantom upper limb (Percy J., Q.E.H. #30747), p. 277. Vertebral arterial branches covered the medulla ventral to the spinal accessory rootlets in this second case. Although in this latter patient the incision was to a depth of 6 mm. and may have provoked the pain by damage to quintothalamic fibres, it was only carried to the standard 3 5 mm. depth in the first. Furthermore, paraesthesias occurred in 13 out of the 16 of our patients with trigeminal neuralgias of various types whose tractotomies yielded adequate relief of the original pain. In most of the patients the degree of annoyance was minor or transitory; often it was brought out only by direct questioning. The sensations were described in various patients as "unpleasant tingling," "itching," "sensation on the lips like too hot mustard on the tongue," "irritated sensation," "creeping feelings," "like a little animal crawling on the skin," "throbbing, frozen sensation," "burning," "tickling," "pleasant feeling of warmth," "pressure sensation."

These troublous sensations never appeared immediately, usually not within the first few weeks, and not for nine months in one patient. They tended to increase in severity for several months, then gradually became less noticeable; in only two of the cases of trigeminal neuralgia were they present in significant degree after three years. As both of these patients eventually developed psychoses with multitudinous complaints referred to many parts of the body, the paraesthesias referred to the operation were hard to evaluate. During the first three years after operation the dysaes-

individual after tractotomy also showed the clearcut presence of some sensation by noting further changes on instilling 2 per cent cocaine into the eye one drop at a time. The sense of touch provoked by 1 mg. of sulphanilamide powder became progressively less when tested between each drop, until finally 10-20 mg. of sulphanilamide powder gave rise to no sensation and the patients tended to ignore its presence. The same large amount of sulphanilamide powder on the totally anaesthetic cornea of a patient after trigeminal rhizotomy was similarly ignored. The proof of the efficacy of the sensation remaining in the cornea after tractotomy has been the fact that not one of our patients, or of those of any other authors whom we have cited previously, has had even a mild keratitis. Guidetti (1950) reports "slight neuroparalytic keratitis" after two of 124 operations—"due to the patients' own carelessness."

Three of our men have had especially thorough trials of their corneal protective mechanism. One (William B.) has worked steadily in a carpenter shop and goes to an emery wheel 30 to 40 times a day. Although once a bit of emery dust in his eye was first spotted by another workman, who removed it, he knows of no other occasion when he has ignored a foreign body in the eye. Another patient (Charles C.) has worked in a precision metal grinding shop. He has always known whenever he gets a bit of metal in the analgesic right eye, and has had it removed at once—in fact he prefers having the metal get into that eye because it does not hurt at all as it does on the other side. Neither patient has even had any redness of the eyeball on the tractotomized side in the 10 years since operation, during all of which time each has been at his regular job. The third man (Edward G.) has also worked at carpentry for six years after operation with equal freedom from ocular symptoms. Such experiences constitute a strong argument for tractotomy in a young active person whose first trigeminal division must be rendered analgesic if pain is to be relieved.

iv) Disadvantages of the operation:—The major drawback of tractotomy is the difficulty in cutting all of the descending trigeminal tract at the desired level. The tuberculum cinereum is recognizable in a formalin fixed specimen stripped of its pia, but is far more difficult to identify *in vivo*. Olivecrona (1942), in a series of 34 cases of trigeminal neuralgia, in nearly all of which he made the incision 2-5 mm. above the obex, produced analgesia in all three divisions in only 17 out of 37 sides of the face. As he lowered the level of his incision he produced a slightly less consistent analgesia which was complete in all three divisions in only five of his medullary incisions in operations for migraine (1947A). Five of the remaining 10 incisions yielded analgesia of the first two divisions, and in the remaining five there was sparing of the first as well as of other divisions. Corresponding with the failure to maintain analgesia he has had a 30 per

thesias were a source of real exasperation to two other patients (Charles C. and Theresa G., Table XXVI), whose introspective natures led us to perform tractotomy in preference to rhizotomy. Fortunately these sensations then subsided and they have been virtually free of them for the past seven years. One of our patients with a malignant tumour (Norman G.) had such bad itching at the medial end of his lower eyelid that he scratched off the skin there, but pain in this area was also intense so that the paraesthesia alone may not have been responsible. In two of our patients, operated upon at the gracious invitation of Sir Geoffrey Jefferson at the Manchester Royal Infirmary, tractotomy was performed on the second side after rhizotomy had been done on the original side. One of these patients definitely preferred the mild paraesthesias of the tractotomized side to the more severe ones on the side of rhizotomy. The other patient, a phlegmatic lady, at first did not "mind much" the postoperative sensation on either side, but she always chewed her food on the side on which touch was preserved and, nine-and-a-half years later, tells us the paraesthesias on the rhizotomized side have become much more of a burden than those on the other side. While our experience does not permit us to urge a blithe disregard of the postoperative paraesthesias, it seems likely that even if they are bad for a time they will probably disappear, and the younger folks in particular can then harvest the full benefit of their patience.

Another of the possible advantages of the procedure, elimination of the neuroparalytic keratitis, has been realized to the fullest degree. Sjöqvist (1938A) first described the corneal reflex as absent (cases 2, 5 and 9) or almost completely absent (case 4) after tractotomy producing analgesia of the first division. This statement was substantiated by Rowbotham (1938, three cases), Walker (1939, one case), Smyth (1939, one case) and by Olivecrona (1942; corneal reflex lost in 13 cases; diminished in three, and normal in one). In our nine cases done in 1942 and 1943 we noted that during the first few days postoperatively, when a pin-head was allowed to rest on the cornea, the patient was unable to tell when it was touching this structure and there was no reflex closure of the eyelids. However, there was gradual recovery of sensation so that in about one month the patients could tell accurately when a pin-head was resting on the cornea, even though it caused no blinking of the eyelids in most of them. The utility of this degree of sensation was tested by the placement of sulphanilamide powder on the cornea. Less than 1 mg. of this powder was appreciated as a touch without painful quality by all of the eight patients so tested; it nevertheless gave rise invariably to blinking of the eyelids and lacrimation until all visible traces of the powder were removed. That a visual cue was not responsible for the blinking was demonstrated by placing the powder near the periphery of the iris and securing the same response. One

he also (1947A) states that "even if analgesia is absolute at the time of operation some restitution of the ability to recognize pain usually occurs within a few weeks."

v) Methods of securing enduring analgesia:—We have presumed that the recovery is largely due to contusion rather than division of fibres, and it seemed that the best chance of achieving permanent analgesia lay in deliberately extending the incision both dorsal and ventral to the descending tract (see descriptive operative technique on p. 198). The high percentage of successes following anterolateral cordotomy appears to be correlated with the fact that one can surround the pain pathway with a generous incision doing little harm (see p. 213). We hoped to apply the same principle to this operation. There appeared to be no good reason for not cutting slightly into the spinothalamic pain pathway ventrally and to ascertain that one had done so by testing the patient's contralateral extremities on the operating table. Furthermore the nucleus of the fasciculus cuneatus lies almost entirely in the closed part of the medulla below the level of the obex; the fibres coming up to it from the spinal cord will have undergone synapse and the secondary afferent neurone will have passed into the decussation of the medial lemniscus by the time the level of the obex is reached. Hence incision into this structure near its rostral end as it lies dorsal to the trigeminal tract ought to produce little or no permanent damage. However, the nucleus externus of the fasciculus cuneatus (nucleus gigantocellularis or magnocellularis of von Monakow) immediately dorsal to the descending tract sends a fasciculus into the restiform body and we were concerned as to the effect of a lesion here (see Fig. 114). But since a generous incision into each side of the bulb of our patient Susanna W. (Table XXVI) had caused little permanent sensory loss, we considered that it must have been made into this region instead of into the trigeminal tract. Since it was without serious sequel, we thought deliberate extensions dorsally might therefore be safe.

With the above facts in mind, we carried out nine bulbar tractotomies in 1942 on an especially selected group of younger patients, employing an incision 3 mm. deep beginning in an avascular spot at or just below the obex, and carried from a point just ventral to the line of emergence of the cranial XI rootlets dorsally through the trigeminal fibres and nucleus well up into the nucleus cuneatus (Fig. 61 and 114). The patients were then tested and, if there was no sensory loss on the opposite lower limb, the incision was begun more ventrally and carried up into that previously made. All of these nine patients were re-examined fully three to six years later, and they had maintained virtually all of their original trigeminal analgesia as well as much of the sensory loss in the pharynx and external

cent recurrence rate of trigeminal neuralgia in 101 cases, and a third of these recurrences required reoperation (1947B). The rate of recurrence appears to have been *inversely proportional "to the extent and intensity of* the sensory loss." As the period of follow-up of his patients has lengthened, the recurrence rate has risen to 37.1 per cent of 124 cases (Guidetti, 1950), and of these 59 per cent are more severe recurrences requiring reoperation.

Sjoqvist (personal communication, 1950) produced analgesia in all three *trigeminal divisions in* only four of the 26 patients he has operated on. There was some sparing of the third division in 21, of the second division in 10, and of the first division in seven. Weinberger and Grant (1942) found analgesia in all three trigeminal divisions in 14 of 19 patients following tractotomies, and in general they concluded "that the relief of pain was related to the maintenance of sensory loss." Subsequently Grant (1948) has found that five of the six operations for trigeminal neuralgia were followed by recurrence of pain. Hamby, Shinners and Marsh (1948) record a major recurrence of the trigeminal neuralgia in 21 per cent of 28 patients; they had another six patients with typical but bearable neuralgic pain and five more with occasional fleeting pains in the face; in the majority of their patients incision was made 10 mm. below the obex. They found that the fibres to the tongue, upper lip and side of the nose were the most likely to escape division.

The claim of LeBeau *et al.* (1948) that a complete division of the trigeminal pain pathway is not necessary to suppress tic douloureux is certainly not borne out by the above observations. Falconer (1949) has an impressive series of 17 patients (one bilateral) in whom he produced analgesia of all three trigeminal divisions on 14 sides, and analgesia of the first two divisions plus hypalgesia of the third in the other four sides by incision at or a few millimetres below the level of the obex, made with the patient under local anaesthesia so that his facial sensation could be tested immediately afterwards. Even so, a second operation to complete the incision proved necessary in three cases, and two or more cuts at different cross sectional levels of the bulb were made at the original operation in most cases. The pain has remained relieved in 13 of the 14 sides of the face involved, with follow-up extending up to four-and-a-half years. Our reliance on this technique was disturbed by the experience we had in our first three cases (Susanna W., case 1; Wm. S., case 16 and Wm. O'B., case 19, Table XXVI). These patients, who were awakened at once on the operating table after the incision, had complete trigeminal analgesia but this faded gradually with recurrence of pain in all three. Others have had similar experience; in Weinberger and Grant's case 4 (1942) an analgesia of all three trigeminal divisions as late as the ninth postoperative day had given way to completely normal sensation throughout the face 14 months later. Olivecrona has adhered to the use of local anaesthesia wherever possible, but

he also (1947A) states that "even if analgesia is absolute at the time of operation some restitution of the ability to recognize pain usually occurs within a few weeks."

v) Methods of securing enduring analgesia:—We have presumed that the recovery is largely due to contusion rather than division of fibres, and it seemed that the best chance of achieving permanent analgesia lay in deliberately extending the incision both dorsal and ventral to the descending tract (see descriptive operative technique on p. 198). The high percentage of successes following anterolateral cordotomy appears to be correlated with the fact that one can surround the pain pathway with a generous incision doing little harm (see p. 213). We hoped to apply the same principle to this operation. There appeared to be no good reason for not cutting slightly into the spinothalamic pain pathway ventrally and to ascertain that one had done so by testing the patient's contralateral extremities on the operating table. Furthermore the nucleus of the fasciculus cuneatus lies almost entirely in the closed part of the medulla below the level of the obex; the fibres coming up to it from the spinal cord will have undergone synapse and the secondary afferent neurone will have passed into the decussation of the medial lemniscus by the time the level of the obex is reached. Hence incision into this structure near its rostral end as it lies dorsal to the trigeminal tract ought to produce little or no permanent damage. However, the nucleus externus of the fasciculus cuneatus (nucleus gigantocellularis or magnocellularis of von Monakow) immediately dorsal to the descending tract sends a fasciculus into the restiform body and we were concerned as to the effect of a lesion here (see Fig. 114). But since a generous incision into each side of the bulb of our patient Susanna W. (Table XXVI) had caused little permanent sensory loss, we considered that it must have been made into this region instead of into the trigeminal tract. Since it was without serious sequel, we thought deliberate extensions dorsally might therefore be safe.

With the above facts in mind, we carried out nine bulbar tractotomies in 1942 on an especially selected group of younger patients, employing an incision 3 mm. deep beginning in an avascular spot at or just below the obex, and carried from a point just ventral to the line of emergence of the cranial XI rootlets dorsally through the trigeminal fibres and nucleus well up into the nucleus cuneatus (Fig. 61 and 114) The patients were then tested and, if there was no sensory loss on the opposite lower limb, the incision was begun more ventrally and carried up into that previously made. All of these nine patients were re-examined fully three to six years later, and they had maintained virtually all of their original trigeminal analgesia as well as much of the sensory loss in the pharynx and external

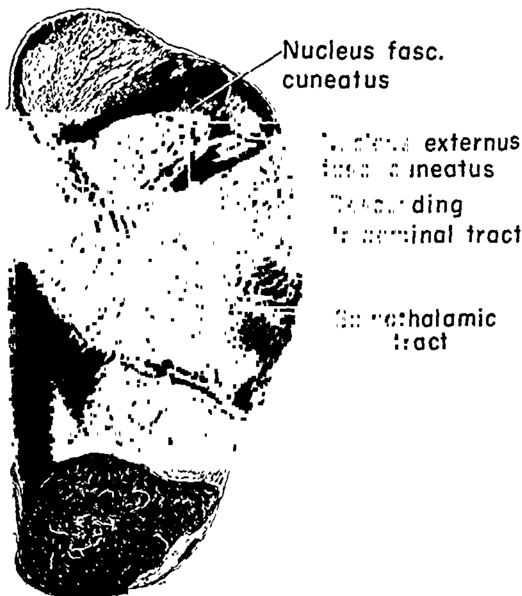


Fig 114 Cross section of the bulb just below the obex.
Site of incision which surrounds descending trigeminal tract indicated by cross-hatched lines.
From W J. S. Krieg's *Functional Neuroanatomy*, 1st ed., 1942. Courtesy, The Blakiston Co., New York.

auditory canal. There has been no recurrence of major pain in any of these patients or in any of the three patients with idiopathic trigeminal neuralgia similarly treated since then. The cutaneous analgesia of the face and head produced by this incision is identical in extent with that which follows total trigeminal rhizotomy (Fig. 115A). In the early postoperative period the analgesia and thermanaesthesia in the contralateral leg has often been as marked as that seen in the same patient (Fig. 115B). However, an equally generous dorso-ventral incision made 6-8 mm. below the obex in four other patients produced total trigeminal analgesia in only one patient,



Fig. 115. Extensive bulbar trigeminal tractotomy.

A (*upper*). Ipsilateral analgesia and thermanaesthesia in Patient Edward G. (Table XXVI, Case 16) 16 months postoperatively.

B (*lower*). Contralateral analgesia and thermanaesthesia in same patient at same time.



Nucleus fasc. cuneatus

Fig. 114. Cross section of the bulb just below the obex.

Site of incision which surrounds descending trigeminal tract indicated by cross-hatched lines.

From W J S. Krieg's *Functional Neuroanatomy*, 1st ed, 1942. Courtesy, The Blakiston Co., New York.

auditory canal. There has been no recurrence of major pain in any of these patients or in any of the three patients with idiopathic trigeminal neuralgia similarly treated since then. The cutaneous analgesia of the face and head produced by this incision is identical in extent with that which follows total trigeminal rhizotomy (Fig. 115A). In the early postoperative period the analgesia and thermanaesthesia in the contralateral leg has often been as marked as that seen in the same patient (Fig. 115B). However, an equally generous dorso-ventral incision made 6-8 mm. below the obex in four other patients produced total trigeminal analgesia in only one patient,

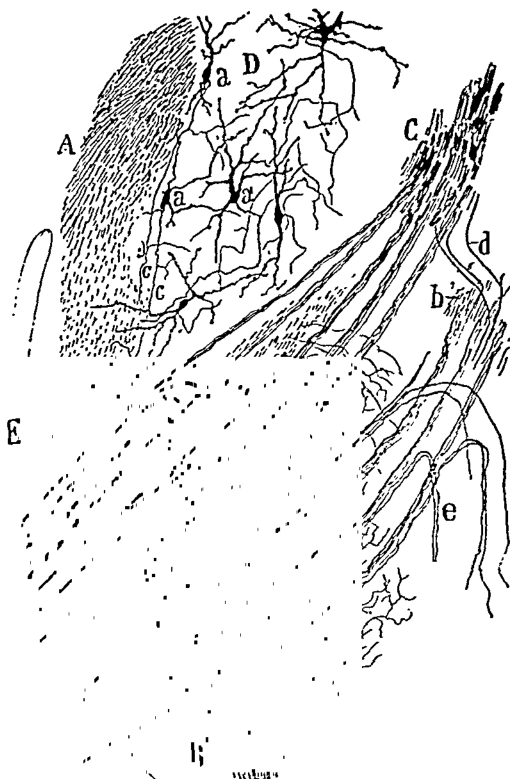


Fig. 116. Cross section of medulla of foetal cat, Golgi method.

A, restiform body; B, descending tract of trigeminal nerve; C, tractus solitarius; D, nucleus of vestibular nerve; E, fibres from dorsal portion of entering glossopharyngeal or vagus nerve leaving the main bundle and joining descending tract of trigeminal nerve; e, nucleus ambiguus; f, nucleus of descending tract of trigeminal nerve.

From Cajal, 1909. Courtesy, Librairie Maloine, Paris.

the evidence favours the distribution first mentioned by Bregman, individual variations occur and the incision may have to be extended in the reverse direction to that ordinarily indicated to obtain the desired result. In particular the dorsoventral disposition of the fibres to throat and external auditory canal is in doubt, and has never been studied by histologic methods in man. In any event our results make it far more logical to improve the analgesia by lengthening the original incision near the obex in a dorsal and/or ventral direction, rather than to make an entirely new incision 2-3 mm. caudal or rostral to the one previously made. The latter tactic urged by Olivecrona and by Falconer may produce unnecessary trauma to the bulb in the course of redivision of fibres already cut.

vii) Topographic localization within the descending trigeminal tract—rostro-caudal disposition of fibres:—Harrison and Corbin (1942) summarize the evidence from 19 publications regarding the caudal limit of the descending trigeminal tract. In man this extends at least into the C1 segment, possibly into C2, and Déjerine puts it even lower down to C4. That it is only the ophthalmic division which reaches the caudal limit has been concluded by many investigators. The lower part of the maxillary division reaches down to the middle of the first cervical segment and the mandibular division extends only to the cervicobulbar junction, according to Harrison and Corbin. Of more practical importance to the surgeon is the upper level of origin from the descending tract of collaterals concerned with pain passing medially to the nucleus of termination. His incision must lie rostral to the bulk of these collateral fibres, perhaps to all of them, if he is to secure analgesia. For additional data on this important point, the reader should refer to Olszewski's (1950) careful work on the cytoarchitectonic structure of the descending tract which is summarized on p. 194 and in Figure 59. McKenzie's (1953) experience in 41 patients has been that total trigeminal anaesthesia including both skin and mucosa was less likely the further below the obex the incision lay. The analgesia was incomplete in 18 of the 41 sides in his group. It would appear that the highest level of termination of collaterals is also lowest for the ophthalmic division, next lowest for the skin of the maxillary division, and the highest for the skin *supplied by the mandibular division. This statement is based on the findings* of Sjöqvist (personal communication, 1950), Hamby *et al.* (1948) and Olivecrona (1947*B*) that incisions several millimeters below the obex are most likely to produce analgesia of the first division, less likely to produce this in the second division and least likely in the third. There is no agreement as to the precise levels for each of the three divisions, however, since Raney *et al.* (1950) say that an incision 4-5 mm. deep slightly above the first cervical nerve suffices, whereas our extensive incision near the obex did not

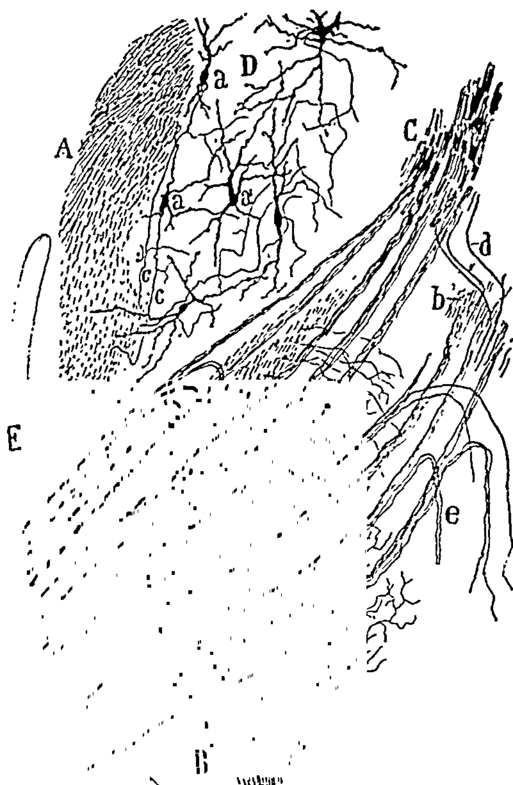


Fig. 116. Cross section of medulla of foetal cat, Golgi method.

A, restiform body, B, descending tract of trigeminal nerve, C, tractus solitarius; D, nucleus of vestibular nerve; E, fibres from dorsal portion of entering glossopharyngeal or vagus nerve leaving the main bundle and joining descending tract of trigeminal nerve; e, nucleus ambiguus, f, nucleus of descending tract of trigeminal nerve.

From Cajal, 1909. Courtesy, Librairie Maloine, Paris.

yield total trigeminal analgesia in patients Dorothy G. and Antonio O.

Our own cases demonstrate that there is in addition a tendency for the fibres to the oral mucosa to terminate at more rostral levels than do the fibres to the skin of the same trigeminal division, whereas Weinberger and Grant (1942) think that the pain fibres from the oral mucous membrane lie most medially in the tract. But in our patients Ellen K., Ruth P. and William W., with incisions 4-8 mm. below the obex, and in Dorothy G., with incision near the obex, analgesia was found in the skin but not in the oral mucosa supplied by the second division. Return of severe paroxysms with a trigger point in the normally sensitive upper gum occurred in William W., the only patient in our series with idiopathic trigeminal neuralgia whose extensive incision was followed by a return of severe pain. Of those with incisions at or just below the obex, patients Susanna W., Ethel D., Elizabeth M., Edward G. and Norman G. each had analgesia of the skin of all three divisions, but only hypalgesia of the oral mucosa supplied by the third division. In Susanna W. the second division's oral mucosa was merely hypalgesic. Production of analgesia of the external auditory canal and oral pharynx was even more inconstant following our incisions near the obex, and occurred in only one of our patients with incisions more than 5 mm. below the obex. Thus in William B., Selina S., Edward D. and Edward R. (Table XXVI) and in Percy J. one or more portions of these areas showed only hypalgesia, even though the entire trigeminal skin and mucosa was analgesic. Moreover no patient with incomplete trigeminal analgesia showed permanent analgesia of the oral pharynx or external auditory canal. As would be expected from the fact that the trigeminal nerve often contributes substantially to the innervation of the anterior wall of the external auditory canal, this was more often analgesic than was the posterior wall. From these findings we conclude that the pain pathways from the oral pharynx, tonsillar fossa and external auditory canal terminate in the descending cephalic pain pathway ("trigeminal tract") more rostrally than do those travelling with the trigeminal nerve. If one is to use this operation in an effort to relieve pain in these areas one should perhaps incise even more rostrally than the obex.

viii) Entry of pain and temperature fibres from nervus intermedius, glossopharyngeal and vagus nerves into descending trigeminal tract:—Cajal (1897), from his Golgi preparations in the foetal cat (Fig. 116) and the newborn mouse, had described small bundles of fibres leaving the glossopharyngeal or vagus nerves as they enter the bulb and joining the spinal trigeminal tract, of which they form the dorsal 1/6th or 1/7th. Van Gehuchten (1900, Vol. 2, p. 77) doubted the existence of such a course for glossopharyngeal or vagal fibres when he was unable to find any degeneration in this descending trigeminal tract after cutting the ninth and tenth

nerves outside the bulb. Cajal (1909, Vol. 1, p. 730) then reviewed his Golgi preparations, reasserted the existence of the trigeminal fascicle leaving the ninth and tenth rootlets, and suggested that his observations and those of van Gehuchten would be in agreement if the fibres he saw were motor. However, the sensory testing in our cases with extensive incision near the obex during 1942 and 1943 revealed one month or more after operation analgesia of the oral pharynx, tonsillar fossa and pillars of the fauces in seven of the patients, and severe hypalgesia in one more out of a total of 10. Of the remaining two patients the gag reflex in Ethel D. was so brisk we could not test her, leaving only Selina S. in whom an incision carried well dorsally near the obex definitely did not produce marked loss of pain in the oral pharynx. Furthermore, one of the patients, Charles C., complained of pain in the back of his throat on the side of his incision at operation. Temperature sensation in this same area was also impaired, but its exact degree was hard to assess because the preservation of touch in the area leaves the patient with a gag reflex. One of our patients noted that, while hot or cold fluids were passing down his throat, he was able to determine their temperature only on the side opposite the lesion.

In seven of these patients appreciation of pinprick and of hot and cold was lost on the anterior wall of the external auditory canal, and in one more it was severely impaired. This might have been a component of the trigeminal analgesia, but the posterior wall of the external auditory canal was analgesic in six of the patients, and markedly hypalgesic in two of them — a loss clearly due to division of afferent fibres travelling with seventh, ninth or tenth nerves. The only patient (Ethel D.) known to have escaped pronounced long-term sensory loss in the external auditory canal had an incision which was carried dorsally only to the point of producing analgesia in the canal at the time of operation. Apparently these contused fibres later recovered. On the external surface of the tympanic membrane a 2 gm. point on the side of the incision gave the impression of a crackling or other noise, but caused no pain or discomfort; on the normal side a 1 gm. point felt sharp It was apparent that Cajal's original conclusion from his cats and mice that sensory fibres from the vagus and glossopharyngeal nerves join the trigeminal tract was correct and applies to man. Since we have often found the external auditory canal analgesic or hypalgesic, we presume that the pain fibres in the nervus intermedius take the same course. Cajal, *however* (1909, Vol. 1, p. 851), saw no axones leaving the nerve of Wrisberg to pass into the descending root of the trigeminal nerve. We began to utilize our observations in 1944 in the treatment of pain from carcinoma affecting the deeper portions of the head and face, and in 1945 in the treatment of attacks of idiopathic neuralgic pain referred to the external auditory canal. Brodal

(1947A) was the first to publish similar observations in four patients operated upon by Torkildsen in 1945.

ix) Completeness of relief of trigeminal neuralgia when analgesia is present: Olivecrona (1942, case 11) was the first to point out that a patient might still complain of his original neuralgic pain following trigeminal tractotomy, even though there appeared to be complete trigeminal analgesia. He has since had this experience in five cases (Guidetti, 1950). Raney *et al.* (1950) report in nine of their 59 cases "sudden touch sensations equivalent to the painful preoperative attacks" upon stimulation of analgesic zones which had been trigger areas; pain, however, was not felt. Of 13 of our patients with analgesia and with adequate relief of their idiopathic trigeminal neuralgia, [illegible] time during their postoperative course of [illegible] provoked by external stimuli. On the basis of our experiences after partial trigeminal rhizotomy we have presumed that this presaged a return of the original syndrome with full vigour, much as occurred in a number of patients of Hamby *et al.* One of our patients said the sensation was that of the original attack "in miniature." To our gratified surprise these pains have remained mild and infrequent, and have not blossomed forth in a single instance into the serious complaint we anticipated. In four of these patients the attacks subsided and did not recur; the other four are now in the ninth or tenth postoperative year; and three of them have had about the same degree of inconsequential pain for seven to nine years. We are beginning to hope that this means that their adequate, if not perfect, relief of pain will be permanent, following the drastic type of incision into the bulb which we have used.

x) Effects of damage outside of descending trigeminal tract: As the incision has been moved caudally into the closed portion of the medulla just below the termination of the fourth ventricle, the laryngeal paralysis and severe lasting ataxias have almost disappeared. Falconer describes a slight but permanent ataxia in six of his 20 cases which, however, was not troublesome. The disturbances in equilibrium present initially in 17 of Olivecrona's first 30 cases with incisions rostral to the obex, gradually disappeared within a few months, with the exception of a single patient in whom an intradural haematoma developed and of three others in whom marked improvement occurred. Of the 84 patients in whom his incision was at or below the obex only 19 per cent had any incoordination, dysmetria or weakness of the ipsilateral limbs or lateropulsion to that side. These disturbances disappeared within a few weeks in all but one person, in whom they lasted several months (Guidetti, 1950).

Our incisions carried well into the nucleus cuneatus at or near the obex produced initially a wild ataxia and weakness of the ipsilateral upper limb in

15 out of 16 cases, including those in the group with pain from malignant tumours. On the first postoperative day the patient was likely to miss his head completely, or to have the hand flop abruptly against his face on the finger-nose test. These erratic movements steadied down and the accompanying weakness receded rapidly. In the patients with trigeminal neuralgia coordination was virtually normal by the end of two months in all but two instances. One of these was the oldest patient of the series, aged 75 years, in whom three to four months were required for recovery. In the patients enfeebled by carcinoma one of these also required three months for recovery. We presume this clumsiness confined to the upper limb is due to division of some of the fibres entering the nucleus magnocellularis of von Monakow, the structure for the upper limb analogous to the cells of Clarke's column in the thoracic spinal cord for the lower limb. A striking tendency to fall toward the side of the lesion when first sitting up in bed, and later when walking, occurred in the same 15 patients. This lateropulsion, almost as bad with the eyes open as closed, tended to be troublesome a month or two longer than the unsteadiness in the arm; nor did it regress as completely. In later years when the patients had an attack of grippe, or became fatigued, they might find that they had to concentrate on avoiding some deviation in walking. One woman nine years later carries an umbrella whenever she leaves the house for support if need be. In two of our patients, Emily S. and Edward D., multiple (disseminated) sclerosis was thought to be the cause of a moderate spastic weakness of both legs for years prior to operation. Both patients were just able to walk preoperatively and regained this ability within six weeks and one month respectively. This was a pleasant surprise since we feared a protracted handicap might ensue. The extreme disturbances in gait initially present have subsided and have not once been a sequel of any consequence.

These 16 patients of ours also mentioned, during the first few weeks after operation, a subjective numbness, sometimes a tingling or "electric" feeling in the thumb and index finger of the ipsilateral hand, less often of the whole forearm, hand and fingers. This was never a cause of any inconvenience and was usually unaccompanied by any demonstrable objective change in sensation. Stereognosis, graphaesthesia, two-point discrimination, proprioception and the sensory threshold for touch as tested with calibrated hairs were all checked in the fingers, and were nearly always normal.

In one of our patients there was intermittent vomiting which lasted for nearly a year. We had reason to suspect a psychogenic factor in this woman, but her incision was made to a depth of 4 mm. while in all of our other cases it was no deeper than 3 to 3.5 mm. Possibly this slight further encroachment upon the nucleus ambiguus may have been responsible for the vomiting. This sign was also present for seven to 10 days in two of the patients of

Hamby *et al.* (1948). In one of Olivecrona's 34 cases (1942) a haematoma formed around the medulla and cerebellum and this patient had vomiting, giddiness and inability to walk for several months.

Hiccoughs have been commented upon occasionally. For example, in five of 19 cases of Grant and Weinberger (1941A) they lasted three to nine days and were very exhausting in two instances. Several of our patients have had briefer periods of this as a minor annoyance. Transitory herpes, usually on one or both lips, occurred postoperatively in about half of the cases of Falconer (1949) and Hamby *et al.* (1948). The eruption may even appear following tractotomy in a region previously rendered anaesthetic by rhizotomy (Sjoqvist, 1938A, Case 2). As is the case after trigeminal rhizotomy, it is of no clinical consequence. A Horner's syndrome on the side of the bulbar incision was seen in six of Olivecrona's patients (Guidetti, 1950), and occurred in many of our patients. This sympathetic paresis usually recedes within a few months, and of course never causes inconvenience.

Other complications mentioned by Hamby *et al.* are psychic depression in five patients, disorientation in two, hallucination in one and hysterical quadriplegia for one year in one instance. One of the patients of Grant and Weinberger with painful carcinoma developed a persistent postoperative psychosis. Raney *et al.* mention postoperative anxiety reactions in nine instances. These arose from the fact that stimulation of the previous trigger areas caused sudden touch sensations equivalent to the painful preoperative attacks. When the patients realized that pain would not occur their anxiety ceased. Hamby *et al.* report six patients with unexplained fever for seven to 14 days after operation. An "aseptic meningeal reaction" with a high count of white cells in the cerebrospinal fluid and no growth on culture media occurred in two of our patients.

Our series of tractotomies differs from others by its deliberate extension ventrally into the spinothalamic tract, as well as dorsally into the nucleus cuneatus. Others have unintentionally produced a contralateral analgesia and have commented that it caused no complaint or disability, for example, Raney *et al.* (1950) in three cases and Sjöqvist (personal communication, 1950) in four cases. In 26 of our patients in whom contralateral sensory loss followed our trigeminal tractotomy the same lack of disability therefrom was noted in most of the cases. We attempted to damage only the dorsolateral part of the zone containing secondary afferent pain fibres so that the initial analgesia, which might extend as high as the midthorax as well as throughout the lumbar and sacral segments, soon receded in most instances. As would be expected the analgesia was most persistent in the lower lumbar and upper sacral segments.

A perversion of sensation in the zone innervated by the injured spinothalamic fibres was seen in a few patients, but was usually slight

Charles C., William B. and Ruth P. all had stinging or tingling, burning sensations when areas on the lower limb were rubbed, and they tended to pat these regions dry after a bath instead of using the towel more vigorously. In two patients with an extensive contralateral sensory loss right after operation more troublesome paraesthesias developed. In patient Peter T. (p. 476), who had an analgesic thermanaesthetic zone from L1-S5, there was a change after three years in that pinprick caused a diffuse unpleasant feeling, a much more annoying sensation than was elicited by pinprick on the opposite normally innervated limb. When he walked he had "an empty sensation with a mild electrified feeling" of most of the lower limb from the knee down. By 1952 this sensation had become "a burning pain from hip to toes," "very uncomfortable whilst walking about." Patient Bessie J., who had analgesia of her leg just after operation, has also had a gradual progression in the severity of her paraesthesias with recession of the analgesia. Ten years after operation she says that the stinging in her leg is so bad that on some days she can hardly walk. Guidetti (1950) records a worse experience in a patient whose bulbar trigeminal incision was followed also by "decided diminution in the sense of touch, pain, and temperature" as far up as the third cervical segment. Painful burning paraesthesias developed in this whole area three months after operation. As in our patients, they were not spontaneous, but were provoked by pressure in the affected side as when sitting; they persisted in his patient five years after operation.

These experiences suggest that an extensive analgesia after division of bulbar spinothalamic pathways will not only fade, but may give rise to paraesthesias which become progressively worse over the years rather than quieting down,* as do the paraesthesias related to division of the primary afferent neurones in the trigeminal tract. Consequently we favour extending the incision into the spinothalamic zone only to the point of producing hypalgesia at operation. In the great majority of our cases, in which the contralateral analgesic area soon diminished markedly, the paraesthesias were inconsequential.

xi) Bulbar tractotomy in bilateral trigeminal neuralgia:—Harris (1940A) has seen 85 bilateral cases, an incidence in his series of 5.3 per cent. The second side may become affected only some years after the original onset. Olivecrona (1942) was the first to demonstrate the feasibility of making an incision into the trigeminal tract on each side of the medulla at the operation. He carried this out in two patients, and produced an analgesia of satisfactory extent on three of the four sides. In one of the patients there was a protracted disturbance of gait. Raney *et al.* have carried out the

*We have had identical experiences in cases of spinothalamic tractotomies in which the analgesia has faded to a pronounced extent (see page 255) and it would seem that the tendency to this complication increases the nearer the thalamus the tract is cut.

bilateral one-stage operation in a single patient with analgesia of both trigeminal zones and an uneventful convalescence. In our one attempt (Susanna W.) an inadequate incision was made on each side. Falconer has performed successful tractotomies one-and-a-half years apart on opposite sides of the same patient, and has used this operation on the second side a year after a Gasserian alcohol injection on the other. In our patients Dorothy B. and Emily S. a trigeminal rhizotomy on one side was followed by a successful tractotomy on the other. Even if the original rhizotomy or alcohol injection has left corneal sensation and the masticatory innervation intact, an anaesthesia of the second and third division areas on the second side is a major handicap. Such bilateral anaesthesia precludes normal eating habits; the patient feels as though he is shovelling food into a void, and at best can train himself to eat while sitting in front of a mirror.

Our single experience with bilateral posterior rhizotomy in the middle fossa has convinced us that this operation is inadvisable, no matter how skillfully it is carried out. This woman (Dora V., M.G.H. #734929), 20 months after the second denervation for bilateral second division tic, complains bitterly that liquids run out of her nose and escape from between her lips, as well as of paraesthesias in her face, although it was possible to preserve sensation in her right cornea and right side of her tongue, and there was no injury to the motor root on either side.

xii) Indications for bulbar trigeminal tractotomy:—We think there are only two clear-cut indications for this operation. a) *Bilateral trigeminal neuralgia; in this condition it should be performed on at least one side,* so that the preservation of touch on the tractotomized side will permit normal intake of food, which is difficult with total anaesthesia of the mouth. b) *Onset of pain or a trigger zone in the first division in a relatively young or vigorous person, or in one whose eye on the other side is blind.* The persistence of an effective corneal reflex is of special value in such people.

CHAPTER XV

GENICULATE, GLOSSOPHARYNGEAL, AND VAGAL NEURALGIAS

A. GENICULATE NEURALGIA

THERE IS EVIDENCE that pain fibres from the geniculate ganglion supply a portion of the ear, the deep structures of the face and head, and the facial musculature.

For eight years, from 1907 onwards, Ramsey Hunt (1915) published a series of studies in which he determined, largely by the location of the eruption of herpes zoster, the cutaneous and mucosal regions supplied by the geniculate ganglion of the nervus intermedius, as well as the ganglia of the glossopharyngeal and vagus. The analyses in relation to the geniculate ganglion are especially convincing because the swelling of the ganglion in the bony facial canal usually produced a facial palsy, often with auditory symptoms. Hence one could be reasonably certain that this particular ganglion was affected. On the basis of 35 such cases studied by himself, or collected from the literature, Hunt placed the cutaneous zone of the nervus intermedius on the lateral and slightly on the medial surface of the auricle as shown in Figure 117. He included also a strip in the external auditory canal and on the tympanum, as well as an intraoral remnant of distribution on the soft palate and anterior two-thirds of the tongue as indicated. He emphasized that the extent of the geniculate innervation is highly variable, in line with its vestigial character as a sensory remnant in a phylogenetic development in which the trigeminal and cervical cutaneous sensory zones have encroached more and more on that of the facial nerve. He was also careful to point out that mild inflammatory reactions may have occurred in adjacent ganglia in some of his cases to confuse the interpretation.

Further evidence that the nervus intermedius has sensory components distributed as described above lies in the hypaesthesias which may appear for a short time following facial palsy of Bell's type. If present these are most likely to be found on the concha, much less often on the medial surface of the auricle and anterior two-thirds of the tongue. The nebulous character of this sensory supply to the ear is apparent from the fact that a cutaneous branch of the facial nerve has not been demonstrated in adult man, although Rhinehart (1919) has recorded this structure in serial sections of the head of the albino mouse, and Fenton and Larsell (1928) have seen such a branch

in sections of a 54 mm. human foetus. Such fibres may travel in the adult man in the posterior auricular branch of the facial nerve or in the long described anastomoses between this nerve and the auricular branch of the vagus, or even in the auriculo-temporal branch of the trigeminal. Hovelacque and Rousset (1922) have described from their dissections the numerous variations in the relationships of these nerves found in man.

Other afferent fibres from the geniculate ganglion pass a) via the greater superficial petrosal, or b) in the branches of the facial nerve going to the facial muscles. Although any vestigial pain fibres passing to the tongue might travel with the gustatory fibres in the chorda tympani, they seem too insignificant to produce clinical symptoms.

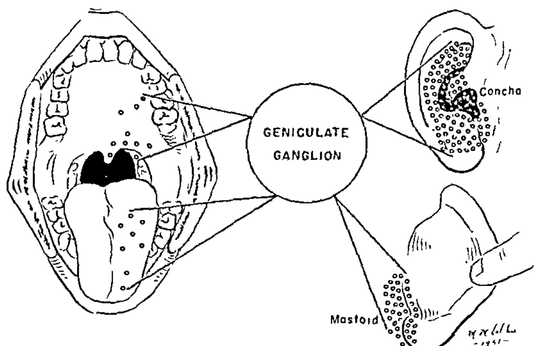


Fig 117 Sensory distribution of fibres passing via nervus intermedius through the geniculate ganglion.

These diagrams show the locus in the mouth and on and behind the ear of herpetic vesicles which may occur in zona of the geniculate ganglion.

Adapted from Hunt: *Brain*, 1915, by permission of the editor.

A few cases give clear-cut proof that the nervus intermedius may be *implicated in a neuralgic type of pain referred to the ear. The first of these* was reported by Clark and Taylor (1909) as "true tic douloureux" of this nerve, although the long duration of the attacks of pain and the absence of provocation of a clinical attack on external stimulation are atypical for that diagnosis:

The patient, a young woman, began in 1907 at age 28 years to have attacks of pain just in front of the left ear. Later the pain was referred as well to the depth of the ear on the anterior wall of the external auditory

canal. A milder pain was also present throughout the face and in the occipito-cervical area on the same side. This more diffuse pain diminished in five or six months and was present only intermittently in the next year, but the attacks of pain in the ear became so severe that the patient was finally taking 800 mg. of morphine per day. The attacks lasted from a half to three hours; occurred at first only weekly, later daily or oftener. The external auditory canal was "sensitive to touch," but it is not definitely stated that this stimulus would bring on a typical attack of pain. On April 23, 1909, Dr. Alfred Taylor operated and felt that he had divided the VIIth, the nervus intermedius, and the upper fasciculus of the VIIIth nerve. A complete facial palsy ensued, but since this began to recover in five months and later recovered fully one is inclined to suspect that not all of the fibres of the facial nerve were cut. The left ear was deaf for four days; then hearing on this side returned to normal in the following week. On the twelfth postoperative day she suffered two hours of severe pain in the left ear like that present preoperatively, but the patient then remained free of pain for the six years she was followed. A finger inserted into the left auditory canal was no longer painful. Sensory examination of the face and external ear were otherwise negative. A cerebellar ataxia in the early postoperative period cleared up completely. Some critics of the validity of accepting this case as one of geniculate neuralgia have attributed the cure to "the decompressive effect of the operation." However, as Furlow pointed out, Taylor closed the dura and replaced the bone flap he had turned down (now an unusual procedure), hence no decompressive effect of the operation was likely.

This patient's clinical picture was strikingly similar to that of Reichert's (1933B) patient with glossopharyngeal neuralgia (see p. 484) and the two patients, as well as others we shall describe, illustrate the difficulty in distinguishing clinically between involvement of the nervus intermedius, the glossopharyngeus and the vagus as a cause of pain in the ear.

Furlow (1942) has treated successfully the most typical "tic douloureux" of the nervus intermedius yet reported:

Miss E. M., a young woman, began in November 1939 to have a "lightning variety" of painful spasms deep in the left ear. The pains came and went quickly, occasionally shot in back of the ear. Infrequently some pain irradiated around the left eye. There was never any pain in the throat or neck, nor was the principal pain deep in the ear ever produced by swallowing, talking, eating or any other ordinary activity. By November 1941, cocainization of the sphenopalatine ganglion and treatment by Dr. Costen for relaxation of the temporomandibular joint had proven ineffective. Previous neurological and otological examinations had been normal, but special sensitivity of a small area on the posterior upper quadrant of the external auditory canal just lateral to the eardrum was then noted. When this was touched the patient's typical tic-like pain was reproduced and cocainization of this

spot stopped all spontaneous and induced pain during the period of anaesthesia.

At operation in the posterior fossa under local anaesthesia touching of the IXth rootlet was carried out four times. This caused severe pain in the throat each time, radiating to the ear once only, but the patient said that this was not the typical tic pain. Touching the group of nerves entering the internal auditory meatus at once caused severe pain in the ear identical in all respects with the clinical pain. When the rostral half of the VIIIth nerve was picked up on a blunt hook the patient experienced only dizziness and nausea; when the caudal half was handled she had only roaring in her ear; but when the nervus intermedius, after separation from the VIIth nerve, was touched she complained bitterly of pain in her ear and cried out with this pain when the ramus was cut. Swabbing the patient's left external auditory canal then caused no pain at all, nor did any recur subsequently. Postoperatively there was no facial weakness or loss of acuity on audiometric test. There was no sensory loss on the face, mouth, pharynx, ear or superficial part of the external auditory canal; but deep in the canal and on the eardrum Dr. Costen found diminished appreciation of pinprick and heat, although no anaesthesia was present. The previous trigger zone was not anaesthetic, but touching it failed to produce the original pain. Secretion from lachrymal and from the parotid glands was about equal on the two sides; secretion of the submaxillary and sublingual glands on the side of operation was greatly reduced. When Dr. Furlow last saw the patient three years after operation she was still free of pain and he thinks she has remained so since, a 10 year period. (Furlow, personal communication, 1951.)

Okonek (1951) has recently reported as an example of neuralgia of the nervus intermedius a patient upon whom he operated in 1943. He divided under general anaesthesia what he took to be this nerve and also the whole of the VIIIth. Complete loss of hearing and vestibular function ensued and the previous pain in the ear and face was absent two-and-a-half months postoperatively. *Unfortunately no further follow-up could be obtained:*

This patient, a 42 year old man, had for many years had attacks of pain referred principally to the anterior wall of the left external auditory canal. There were also "certain painful sensations deep in the facial muscles" Apparently because of the latter, surgeons elsewhere had in two operations divided most of the posterior rootlets of V. This had no effect on the pain. The attacks became so frequent that the pain was finally continuous, worse sometimes than others, it was not affected by speaking or chewing. In the postoperative period, after the cutting of the nervus intermedius and VIII, the patient had a slight sticking feeling in the left auditory canal, along with many other complaints which required transfer to a special institution for withdrawal of narcotics. However, two-and-a-half months after the operation he had been off all medication for several weeks. His sensory loss now included the outer part of the anterior wall of the external audi-

tory canal, the tragus and anterior upper part of the helix. A pronounced hypaesthesia was present over the hairless skin just behind the ear.

The sensory loss on the helix and behind the ear is evidence that the nervus intermedius was actually divided, but one should perhaps be wary of classifying this as a proven case of geniculate neuralgia because of the chequered postoperative course and the brief period of observation.

Wilson (1950) has reported as geniculate neuralgia the pains in a woman whom he relieved by division at the same operation of both nervus intermedius and glossopharyngeal rootlets:

> The pain in this woman came on abruptly when she was 46 years old; it began deep in the right ear, radiating to the ipsilateral eye, lips, nose, lower jaw and neck. It was continuous and not aggravated by external stimuli. Over a six-year period pain had been relieved for nine months by an avulsion of the second division of the right trigeminal nerve, and for 13 months by differential trigeminal section sparing corneal sensation. At suboccipital craniectomy under local anaesthesia, the cutting of the glossopharyngeal nerve did not stop the pain. This ceased as soon as the nervus intermedius was divided, and complete relief has persisted for the subsequent follow-up period of over three years (Wilson, personal communication, 1953). Excessive salivation and nasal secretion, present much of the time during her pain, have also diminished to asymptomatic levels since operation.

McKenzie and Keith (1938) have described a patient in whom the nervus intermedius may have been implicated in a portion of the severe neuralgia which originally involved the throat and ear. Intracranial section of the ninth root stopped the pain completely for three to four months, but it then recurred. Four years later the pains were so severe that the intermedius and the upper half of the vagal rootlets were cut, following which the pain has remained absent for several years (McKenzie, personal communication, 1951). The severity of the patient's paroxysms precluded doing this operation under local anaesthesia and McKenzie points out that the vagal rootlets alone may have accounted for the recurrence. In our patient. Mrs. W. (see p. 509), the nervus intermedius may also have been implicated in her aural and mastoid pain.

Rosen (1953) has added two more clear-cut patients with this syndrome. He has developed a new and simple tactic for demonstrating that a branch of the intermedius is involved; he exposes the tympanic cavity by lifting the drum membrane out of its sulcus and folding it upward. Jacobsen's nerve, a branch of the glossopharyngeal, and the chorda tympani branch of the intermedius may then be stimulated separately. In both patients he reproduced the clinical type of pain upon stimulus to the chorda tympani, and relieved the attacks by dividing this nerve. In one patient,

an electrode applied to Jacobsen's nerve caused deep pain in the back of the throat and ear unlike the clinical complaint. In his patients the chorda tympani fibres will presumably regenerate and permit recurrence. We suggest that a delicate bipolar electrode may be applied to the drum in the region of the chorda tympani, and that the patient's response can be effectively determined without employing Rosen's ingenious operative procedure.

In his Case 1, the spasms of pain were referred to the entire external canal and pinna, lasted one to 12 hours and were not precipitated by any of a variety of facio-cephalic activities including swallowing. In his Case 2, involvement of the VII - VIII complex of cranial nerves was indicated by the presence of right-sided tinnitus, slight vertigo, and a bitter taste accompanying each attack of severe pain deep in the right ear.

Bues (1952) has reported, only three months after operation, a patient with complex findings which included much fluctuating pain deep in the ear. His bulbar tractotomy produced analgesia of the external auditory canal and severe hypalgesia of skin over the mastoid process, much of the lateral surface of pinna, posterior third of the tongue, and soft palate. The patient's pain was relieved for the brief period of observation, and there were no undesirable sequelae. Whether the pain here was transmitted over the rootlets of VII, of IX or of X is uncertain.

In collaboration with Sir Geoffrey Jefferson we are reporting an additional case in which the intermedius was involved. This patient is of special importance because of failure of the tactic of selecting the rootlets for section by stimulation at operation under local anaesthesia, despite the unequivocal character of the statements of the cooperative patient:

P.T., male cashier, began in 1928 at age 21 to have attacks of burning pain in the right pinna and external auditory canal. These bouts came on spontaneously unrelated to any known stimuli and each attack lasted from three to 36 hours. The pain was centered in a small area at the inferior boundary of the external auditory meatus and extended inward into the canal "like a red-hot poker being driven into the head." When an attack was present movement of the head increased the pain to an agonizing degree. The patient even had his wife lift him up in bed to have a drink at such times. The pain would stop rather abruptly, whereupon he was able to resume his usual activities at once. Intervals between his attacks, at first about four weeks, decreased till at times they came on successive days. In December, 1943, Sir Geoffrey Jefferson carried out a series of procaine injections during an attack of pain. By blocking the Gasserian ganglion, the great auricular and the lesser occipital nerve, he produced numbness of the face and auricle without useful reduction of the spontaneous pain, touching the ear or external auditory canal still caused intense pain. He exposed the

nerves in the cerebellopontine angle on January 23, 1944, and with the patient awake found that repeated mechanical stimulation of the glossopharyngeal nerve gave the patient pain in the ear, but not of the type nor in the same region as that in his spontaneous attacks. The VIIIth nerve was then held upwards and forwards exposing the tiny nervus intermedius. When this latter strand was lifted up the patient complained at once of severe pain identical with that in his clinical attacks, so the nerve was divided. Postoperatively one found a pronounced facial weakness and deafness, but no definite sensory loss in the external auditory canal, ear or back of the mouth. The patient remained entirely free of his attacks of pain for seven months, when pain of essentially the same type recurred and exceeded its original severity within a few months. Extensive pricking of the external auditory canal and eardrum as well as the pinna did not bring on an attack of pain. The precipitating factors remained unknown.

On June 8, 1945, a bulbar tractotomy was carried out. At the level of the obex a knifepoint 3.5 mm. long was inserted into the medulla just ventral to the line of emergence of the right spinal accessory rootlets and was carried dorsally until it almost cut through the pia over the nucleus of the fasciculus cuneatus. The patient was then awakened from his Pentothal anaesthesia on the operating table and was found to have analgesia of his left lower limb and right face. Bipolar electrodes applied within the external auditory canal caused no pain at 100 volts, even though this caused enough of a burn so that smoke emerged from the external meatus. Twenty volts preoperatively in either external auditory canal had caused pain.

Although this operation has virtually eliminated his attacks of intense aural pain, he has since had a persistent burning paraesthesia present throughout his waking hours, worse in the right eye, bad in the right forehead, present to a lesser degree elsewhere in the right face and even in the left forehead. At times there are acute exacerbations with "terrific electric shock" going through the right eye. The paraesthesias were controlled at night by large doses of barbiturates, but late in 1949 the patient decided to stop all drugs. They persist despite a right-sided analgesia to pinprick of the facial skin corresponding to Figure 115, as well as of the cymba and cavum conchae (the deep fossas of the pinna), the anterior and posterior walls of the external auditory canal, the tympanic membrane, the oral pharynx, soft palate, tonsillar pillars, oral mucosa and lateral, but not medial, nasal mucosa. There is even absence of right facial deep pressure pain upon maximal pressure at the supraorbital foramen, the infraorbital notch, and upon squeezing the upper and lower lip between the examiner's thumb and index finger (examination September, 1948). In 1948 he began to have an "odd sensation" in his previously analgesic left lower limb. This has gradually progressed to become a burning pain in that limb whenever he is walking about. (See p. 469 for other patients with severe paraesthesias in zones of sensory loss after tractotomy for pain in the cord or brain stem.)

The production of this patient's clinical pain by stimulus to the nervus intermedius at operation, plus the relief for seven months which followed division of the nerve by Sir Geoffrey Jefferson, argue strongly that the patient had a geniculate neuralgia, especially since for 15 years prior to that operation the greatest interval between attacks of pain had been four weeks. Whether the additional pathways for the pain in the ear which recurred lay with the IXth or Xth nerves, or as aberrant fibres with the VIIth nerve proper, one cannot say, because all of the cephalic pain fibres in this man appeared to collect in the descending trigeminal tract. This was the first patient in whom we put to therapeutic test the value of our earlier observations in 1942 and 1943 of analgesia in the ear and throat following bulbar tractotomy for trigeminal pain. Because of the persistent severe paraesthesias in the trigeminal zone which followed this tractotomy we should not repeat this operation in another similar case, but would divide nervus intermedius, IX and the upper third of the rootlets of X. This procedure has been carried out with a most happy three-year result in the striking case of Florence W.*

In summary, unless pain deep in the ear can be shown by stimulation to be transmitted exclusively by the nervus intermedius, we advise additional section of the glossopharyngeal and upper vagal rootlets.

B. GLOSSOPHARYNGEAL AND UPPER VAGAL NEURALGIA

1. Clinical Features

Instead of designating the paroxysmal attacks of pain which affect the posterior part of the tongue, oropharynx, and sometimes the ear as glossopharyngeal neuralgia we have used in this chapter's sub-heading a dual title, adding the vagal component for reasons which will appear shortly. Nevertheless, for the sake of brevity we must generally employ the shorter term of glossopharyngeal tic.

The ninth cranial nerve on infrequent occasions transmits bursts of impulses causing terrific paroxysms of pain within its domain. Weisenburg (1910) seems to have been the first to note this in a patient who proved eventually at post-mortem to have a tumour in the cerebellopontine angle Following a retrogasserian rhizotomy for pain in the face and throat, this man was left with stigmata identical with those seen in the idiopathic glossopharyngeal neuralgia, i.e., pain at the root of the tongue, radiating down the throat and to the ear. The attacks were set off by eating, but it was recognized that the precipitating factor was contact of food with a sharply defined trigger zone at the base of the tongue, and not the move-

*By the time of final proof correction her neuralgia had recurred and again required surgical relief—see p. 511.

ments of chewing as in trigeminal neuralgia. The trigger area may also commonly lie in the pharynx, tonsil or ear. It was Harris' (1926, p. 333) original impression that the absence of a trigger zone was characteristic of glossopharyngeal neuralgia and distinguished it from the trigeminal form. As more cases have been reported this differential point has lost validity, but Harris was the first to report cases of the idiopathic type and to give the neuralgia its name. Swallowing (especially of liquids) is more likely to bring on paroxysms than any other activity; talking, sneezing, blowing the nose, coughing, laughing, yawning, shouting, sudden turning of the head and examination of the throat may also cause an attack. Sometimes the patient can arrest the attack by clearing his throat with slight coughs.

The pain is unilateral, usually starts in the tonsillar, pharyngeal or posterior lingual region and often radiates into the ear. When the pains are severe and frequent they may awaken the patient out of a sound sleep at night. In occasional cases the pain may begin in the pinna, the external auditory canal or near the angle of the mandible, and touching or washing the ear or angle of the jaw may precipitate an attack. As in trigeminal neuralgia a severe attack may confer a brief period of immunity lasting a few seconds or more during which the patient may be able to swallow a little food. The duration of each burst of pain is usually less than one minute; but total remissions lasting months or years are common. In fact, in the majority of patients with this disorder whom we have seen, the pain has been too mild to require surgical treatment—in contradistinction to our experience with trigeminal neuralgia. Most of the patients are over the age of 50 years.

This form of neuralgia remains a rare condition; it has roughly 1/70th the frequency of major trigeminal neuralgia in the experience of Spurling and Grantham (1942), but was even less common in Frazier's clinic where he operated on only a single case over a period in which he saw a total of over 2000 patients with some form of "facial neuralgia." Leriche (1949, p. 341) had also operated on only one patient in his entire experience. Dandy (1945), on the other hand, reported 30 intracranial operations for this type of neuralgia. In the 17-year period over which we have accurate statistics, rhizotomies have been carried out in four patients at the Massachusetts General Hospital for classical glossopharyngeal neuralgia in contrast to section of the trigeminal root for tic douloureux in 293 patients.

The cause remains obscure. Peritonsillar abscess has preceded the onset of the pains in some cases (Ray and Stewart, 1948), and a gunshot wound in the tonsillar fossa seemed to be a predisposing factor in a case of Voris and Bakody (1945).

In the *differential diagnosis* one must be especially careful to consider tumours, either intracranial or extracranial, which may develop with pain

of the identical type. In addition to Weisenburg's original case of neoplasm (acoustic neuroma) in the posterior fossa, three of Harris' cases had malignant tumours of the tonsillar area, another probably had a malignant neoplasm, and Davenport's patient (Bailey, 1931) had an epithelioma of the larynx infiltrating the pharynx. German (1938) mentions another patient with acoustic neuroma who had glossopharyngeal pain, and Leriche (1949, p. 341) alludes to a case in which typical neuralgia appeared to be present, but in whom puncture revealed a cyst originating from a pharyngeal extension of the parotid gland. Removal of the cyst cured the neuralgia. Hence careful study of the nervous system and upper respiratory passages should be carried out even in cases with typical "tic-like" pain. Peet (1935), out of a total of 14 cases of glossopharyngeal neuralgia, had five in which he considered this and trigeminal neuralgia to be present in the same individual. The most convincing of these was one in which trigeminal neuralgia had been present and had been relieved by operation prior to the development of a bilateral glossopharyngeal neuralgia which affected the two sides consecutively, never simultaneously.

Temporary blocking of the nerve endings with an anaesthetic agent may aid in diagnosis. Although it has not proved advisable to do an extracranial alcohol injection of the glossopharyngeal nerve at the base of the skull because of its proximity to other vital structures, one can temporarily numb the presumed trigger area in the back of the tongue, tonsil, throat or external auditory canal with 5 or 10 per cent cocaine spray, as mentioned by Adson (1924). If such cocainization stops the outbursts of pain it is the glossopharyngeal nerve which is presumably at fault; this test may be particularly useful in the individual in whom radiation into the anterior tongue or lower gum occurs so abruptly that one is not quite certain where the pain begins. One may also repeatedly use this method of stopping the pain preoperatively in order to build up a patient who is dehydrated and starving because of inability to swallow.

The likelihood of occurrence of both glossopharyngeal and trigeminal neuralgia in the same individual is exemplified by our patient E.E.C (N.E.C.H. #46-885). As the stream of cold water from a drinking fountain struck the back of his throat one day in 1948, this 52 year old architect had an attack of lancinating pain in the right side of the throat. Subsequent stabs of pain in the same spot were brought on so strikingly by swallowing that the patient even expectorated his saliva in an effort to avoid provoking an attack. Pain was also referred to the right temporomandibular joint. This burst of attacks subsided, but in January 1950 there was reappearance of paroxysms of pain referred only to the joint and brought on by talking and chewing. An alcohol block at the foramen ovale producing analgesia of the trigeminal third division has given complete relief in the ensuing 36 months.

We have recently had another patient (O.B., M.G.H. #7834829) with a similar involvement first of IX, then of V. His paroxysmal attacks of pain in the throat on swallowing required glossopharyngeal rhizotomy and, although they then stopped, he developed within six weeks equally severe paroxysms in both the anterior tongue and upper jaw. These have been eliminated by an alcohol injection at the foramen ovale, which fortunately blocked not only the mandibular division but also the Gasserian ganglion.

Another differential point between trigeminal and glossopharyngeal neuralgia is said to be the occurrence in the latter of increased secretion from the parotid gland on the affected side both between and during attacks (Hesse, 1930). Superior laryngeal and geniculate neuralgias (q.v.) must also be distinguished.

2. Treatment

The first successful treatment carried out in three patients by Sicard and Robineau (1920) involved the cutting of the glossopharyngeal nerve, the pharyngeal branches of the vagus and the superior cervical sympathetic ganglion in the neck. However, Adson (1924) found that even when he made an effort to avulse the ganglia of the glossopharyngeal nerve by the arduous extracranial approach, the pain might recur. On the basis of cadaver dissection he then described in detail the simpler and permanent denervation afforded by cutting the rootlets of the glossopharyngeal nerve intracranially. He carried this out in vivo for the first time in 1925 (reported by Love, 1944). Fay (1926) used the procedure for pain in malignant disease. Dandy (1927) treated similarly two more cases of the idiopathic neuralgia and his excellent publication summarized all 20 of the cases in the world literature reported up to that time. When the pharyngeal branches of the vagus are injured or deliberately divided the earlier reports indicate that the patient may have some temporary dysphagia, especially for solid foods (Adson, 1924; Stookey, 1928A; Reichert, 1931); but when the glossopharyngeal nerve alone is cut without injury to other nerves, there is neither dysphagia nor any demonstrable motor weakness in the majority of cases. Stookey, however, did find a permanent lowering of the palatal arch at rest one the side of operation, although the palate could be elevated equally on the two sides. It would appear that in most instances the tiny stylopharyngeus muscle is the only one supplied by this nerve and that its loss of function is not noticeable. This operation usually relieves completely the paroxysms of pain and there has been no case reported yet in which the resultant anaesthesia has been accompanied by the unpleasant paraesthesias which occasionally occur after trigeminal rhizotomy.

The area of anaesthesia in the mouth and throat after glossopharyngeal

rhizotomy was first described by Dandy, who found that the analgesic area covered the zone of reference of pain in the throat, so that he at first thought that vagus section was unnecessary. Figure 64 illustrates the zone which Dr. S. J. Crowe described as analgesic in Dandy's first two cases. A dome of preserved sensation remained in the vault of the nasopharynx, otherwise the tonsillar fossa and pillars of the fauces, posterior third of the tongue and the nasal, oral and laryngeal pharynx were anaesthetic down to and including the posterior (but not the anterior) aspect of the epiglottis, the vallecula and pyriform recess or sinus. On the soft palate a narrow rim on the oral surface and a broader rim on the nasal surface were anaesthetic, as were the Eustachian orifices. The anaesthesia extended *along the Eustachian tube 2 cm. and 2.5 cm. in two cases (Reichert,* 1933B; Dandy, 1927). Taste is usually lost on the posterior third of the tongue. However, in a patient of Furlow's (1942) and in patient I.B. whom we describe shortly, hypalgesia rather than analgesia followed glossopharyngeal rhizotomies which gave complete relief of the pain. Furlow (personal communication, 1951) reports continuing freedom from pain in his case 11 years postoperatively. We presume that overlap from the nervus intermedius or vagus occurred, or that some glossopharyngeal rootlets lie intracranially with those of the vagus. In three patients of Karnosh, Gardner and Stowell (1947) even division of the upper vagal as well as glossopharyngeal rootlets failed to produce any zone of total loss of sensibility to either taste or pain. Similarly in our patient M.P. described on p. 488, glossopharyngeal and extensive upper vagal rhizotomy yielded only patchy analgesia in the "glossopharyngeal" zone. The area of sensory loss usually ends sharply at the midline both posteriorly and anteriorly.

In Doyle's patient (1923) who had had both retrogasserian neurotomy and avulsion extracranially of the glossopharyngeal and pharyngeal branch of the vagus, pain, temperature and touch sensation were still preserved over the posterior half of the nasal cavity and through the nasopharynx above the line drawn through the hard palate. In this operation the tympanic branch of the glossopharyngeal nerve was probably spared, since it arises from the petrous ganglion of that nerve to pass directly into the skull. This one observation suggests the possibility that the tympanic branch of the nerve supplies the nasopharynx as well as the middle ear, and provides still another reason for the intracranial approach and rhizotomy rather than peripheral division.

Fay (1927) studied the results of glossopharyngeal rhizotomy earlier than Dandy. In his case with intracranial section of the IXth cranial nerve plus posterior rhizotomy of C2 and 3, the anaesthesia was the same as that from a cervical rhizotomy alone. In particular there was no demonstrable

change in appreciation of touch, pain or temperature in the pharynx or in the concha of the ear. The sensory overlap here *from adjoining fibres of* VII and X was even more pronounced.

In addition to its sensory component secretory fibres to the parotid, submaxillary and sublingual travel with the IXth nerve, according to Reichert and Poth (1933*B*). Loss of these may not be observed by the patient, perhaps because, as demonstrated by these authors, the chorda tympani *branch of the facial nerve* may also supply secretory fibres (of similar parasympathetic type) to the parotid as well as to the other glands. In the single patient tested by Erickson (1936) there was reduction only in parotid secretion, but not in that of submaxillary and sublingual glands after the glossopharyngeal roots were cut.

The following history will serve to illustrate a typical case of glossopharyngeal neuralgia:

Patient I.B. (N.E.C.H. #57-655), female, aged 66, three months before entry developed a mild febrile illness diagnosed influenza. She had a vague discomfort just below the angle of the jaw on the left which felt "like a gland beginning to swell," but there was no palpable mass. Two months later severe attacks of pain came on, appearing four to five times a day and occasionally awakening her at night. Pains started at the root of the tongue on the left and shot up to the anterior-inferior portion of the left ear. There was no pain in the external auditory canal or in the throat. The pain was "sharp, burning and extremely severe," came on spontaneously or was brought on by talking, swallowing, yawning or eating, lasted but a few minutes. There was no lacrimation, pallor, flushing or sweating with an attack, except that the pain was so bad it sometimes made her cry. Due to forced reduction of food intake she had lost 15 lb. (7 kg.) from 125 to 110 lb. Codeine and aspirin did not stop the attacks of pain. Elsewhere an extraction of four teeth and a procaine injection below the left ear had not helped the pain On examination the application of a tongue depressor brought on a typical attack, but there were no other abnormalities. Application of 10 per cent cocaine to the region of the root of the tongue and tonsillar fossa on the left side eliminated the susceptibility to attacks completely for over two hours. X-rays of the skull, jugular foramina, cervical spine and chest were normal.

At operation on 3/23/51 an attempt to determine by stimulation the reference of pain from the glossopharyngeal, upper vagal and nervus intermedius fibres had to be given up because the patient was too groggy to speak coherently. The glossopharyngeal fibres only were divided, at which time the blood pressure rose promptly from 180/100 to 260/130 (as a consequence of denervation of the carotid sinus), remaining elevated for an hour before returning gradually to the previous figures. The postoperative course was uneventful and she has had none of her original pain nor any other annoying

symptoms in the two years since then. One cannot now provoke an attack even though Dr. Donald K. Lewis finds that she has only hypalgesia rather than analgesia over her left tonsillar fossa and pillars and oral pharynx—a quarter to a half of the stimuli with a 40 gram point feel sharp in these regions, and a 10 gram point is consistently dull here, whereas it is sharp on the right. The posterior wall of the left nasopharynx is analgesic to even greater than a 40 gram point, but a soft bougie passed into the left Eustachian tube feels sharp as soon at it reaches the narrow region about 1 cm. from the orifice. The posterior third of the tongue and the external auditory canal have about normal appreciation of pain. Heat is appreciated promptly on the left tonsillar fossa, but less than on the right. Subjectively liquids seem equally hot on the two sides as they are swallowed.

3. Pain in the Ear: Division of Vagal Rootlets

As we have remarked in the section on geniculate neuralgia, patients with pain confined to the ear present a special problem. Since the tympanic branch of the glossopharyngeal nerve supplies the middle ear, mastoid air cells and Eustachian tube, the involvement of this branch alone by the neuralgic process may cause pain referred only to the depths of the ear. Such was the case for 36 years in a man reported by Jefferson (1931*B*) in whom eventually pain in the fauces appeared as well, and in whom extracranial avulsion of the IXth nerve gave relief. This patient's pain was not excited by anything in particular, nor did he hesitate to press his finger into the auditory meatus to show where the pain was. Reichert's (1933*B*) case of tympanic plexus neuralgia, as he called it, shows features illustrating the difficulties in diagnosis and his excellent method for resolving them:

His patient, a telephone operator, aged 31, had a history resembling that of Clark and Taylor's case (see pp. 472-473) of geniculate neuralgia. In 1921 she had had to discontinue the use of earphones for a short time because of a painful left concha. She was then well until the spring of 1932 when she had a drawing uncomfortable feeling in the left upper part of the face. By August this had extended from the cheek to the forehead and occiput. Coryza at this time was followed in two days by paroxysms, many per day, of sharp stabbing pain deep in the left external auditory canal. In addition to the agonizing pains in the auditory canal, the upper anterior wall of the meatus itched at times and there were aching pains in the left side of the face, nose, eyeball and parieto-occipital area, as well as sensitiveness in the mastoid and pretragal regions. Nothing seemed to induce the attacks nor did salivation occur during them. An initial injection in the region of the sphenopalatine ganglion with procaine was followed by relief for 12 days, but subsequent injections were ineffective. Block of the sympathetic chain from the C7 to T2 level was also fruitless.

At operation under local anaesthesia Reichert moved the bundle containing the left VIIth and VIIIth cranial nerves and found that this evoked pain in the outer part of the anterior wall of the auditory canal, whereas when the IXth nerve was touched the patient shrieked and exclaimed that this produced the tic pain in the deeper part of the anterior wall of the external auditory canal. The IXth nerve was then divided with complete relief not only of her tic but also of the pain in the face and head. The loss of sensation in the pharyngeal area was similar to that observed by Dandy, but there was no anaesthesia of the ear or its external canal.

In this case the failure of stimuli to induce attacks and the generalized facial and cephalic aching set it somewhat apart from the typical trigeminal and glossopharyngeal neuralgias. Erickson (1936) has reported another case similar in that the paroxysms of pain were located either just below the external auditory canal or felt as though a knife had been stuck deep in the ear.

In his case cocainization of the entire pharyngeal area did not stop the pains, nor did any stimulus to the pharynx or external auditory canal provoke them, nor was there a significant difference between the amount of secretion between the two parotid glands even during the bouts of pain. However, glossopharyngeal rhizotomy stopped the pain, produced the typical loss of touch and pain sensation in the pharynx and left the Eustachian tube insensitive to catheterization. Sensation to pinprick in the external auditory canal was not mentioned, but a persistent cough was produced when this region was touched with cotton on the normal side and no such response occurred on the denervated side. Since manoeuvres which brought on pain in this patient increase intrapharyngeal pressure, Erickson suggested that the trigger zone was in the Eustachian tube or middle ear, and that in patients with paroxysmal pain in the glossopharyngeal area, if cocainization of the pharynx does not relieve the pain, it should also be injected into the Eustachian tube and middle ear. Catheterization of the Eustachian tube might also demonstrate a trigger zone.

Another case indicating the variability of the syndrome and the probable need for cutting the upper vagal rootlets, when there is a trigger zone on the concha, was reported by Spurling and Grantham (1942). In this patient there were two trigger zones, one at the palatine tonsil and the other on the concha of the ear and the external auditory canal. Cocainization of the former stopped the pain on swallowing but did not change the trigger area at the ear. Accordingly the upper two rootlets of the vagus as well as the glossopharyngeal rootlets were cut. This yielded anaesthesia of the concha and posterior rim of the external auditory canal, hypaesthesia of the rest of the lateral surface of the ear, except the helix, and marked hypaesthesia in a small area between the eminence of the concha and the

skin over the mastoid. The patient complained of numbness in the ear. There was the usual anaesthesia in the posterior oral and pharyngeal cavities as well. Both trigger areas were eliminated and all of the pain remained absent three years later.*

Dandy (1945) had two cases in which the pain was diminished but not stopped by glossopharyngeal rhizotomy; he reopened the wounds and divided the two upper vagal rootlets, following which pain has been abolished. In his last cases he always included these two vagal rootlets in the section and neither he nor Pastore and Meredith (1949), who did the same more extensive operation in three cases, have seen any untoward symptoms as a consequence thereof. Karnosh, Gardner and Stowell (1947) have also had a patient treated by IXth and later by upper vagal rhizotomy. The second procedure was necessary because of recurrence of pain in the throat which was relieved by cocaine to the external auditory canal. Robson and Bonica (1950) suggest that the need for section of upper vagal rootlets can be foretold by failure of cocainization of the tonsillar fossa to stop pain in the ear, which is then relieved by injection of the nerves at the jugular foramen. They describe a patient in whom this sequence of events took place, and in whom glossopharyngeal rhizotomy left the patient with pain radiating to the ear, a pain which was later cured by dividing the anterior half of the vagal rootlets. Since a test injection at the jugular foramen might be effective by virtue of block of the tympanic branch of the glossopharyngeal nerve, we doubt that it necessarily gives a decisive indication of the need for cutting vagal rootlets.

The authors have divided the IXth nerve in the posterior fossa in four cases of this type of neuralgia. In two patients (O.B. and I.B.) no vagal rootlets were cut, in patient H.N. one tiny rostral rootlet of X was cut; and in patient M.P. the most rostral vagal rootlets, about two-fifths of the total, were cut in two sizeable separate bundles. Radiation of pain to the ear was present in the last three. All four have maintained complete relief. There was no postoperative complication in the first three. M.P. is described in detail on p. 488.

4. Carotid Sinus Reflex with Neuralgia

Cardiac arrest with syncope and, at times, generalized convulsions is another fascinating accompaniment of glossopharyngeal neuralgia. From the carotid sinus, the special sense organ for cardiovascular regulation

*Bucs (1952) has performed bulbar tractotomy in a somewhat atypical patient presumed to have this disorder. The only sensory loss attributable to the operation was analgesia and thermanaesthesia of the external auditory canal and hypalgesia and hypothermanaesthesia of a small zone in front of the ear. Unilateral, almost continuous pains in ear and throat were relieved at the time of report, a scant two months postoperatively.

located at the bifurcation of the carotid artery, comes the sinus nerve of Hering, the afferent pathway of the carotid sinus reflex. This joins the glossopharyngeal. Excessive discharges over the sinus nerve, as well as over the pain path, may occur simultaneously. The reflex effects vary from slowing of the pulse during short attacks of pain to hypotension and even asystole in longer attacks. In the long severe attacks of pain there may be protracted cardiac arrest with absence of pulse, pallor, mental confusion, syncope and/or convulsions. Riley *et al.* (1942) first drew attention to this syndrome. Browder in 1913 (cited by Ray and Stewart) relieved all symptoms in a patient of this type by intracranial section of the IXth nerve. Ray and Stewart (1948) have given the first detailed case report. In their patient pain at the base of the tongue and in the tonsillar region, radiating behind the angle of the jaw and into the ear, was induced by pressure on the neck over the region of the left carotid sinus. Cocainization of the pharynx diminished, but did not abolish the pain. An asystole of 3.8 sec. was recorded by electrocardiogram during an attack induced by swallowing. Pressure on the other carotid sinus was painless and unaccompanied by any change in blood pressure or cardiac rate. Since there was no evidence in this 49-year-old man of generalized vascular disease, so commonly seen in those with carotid sinus syncope, the authors thought the left carotid sinus was probably not hypersensitive. The entire syndrome was cured by glossopharyngeal rhizotomy.

In a similar patient of Roulhac and Levy (1950) convulsions were the prominent part of the picture and the problem was one of determining the cause of epileptic seizures. Detailed questioning revealed the crucial fact that sudden severe burning pain in the left throat and posterior tongue (with no pain in the ear) preceded each seizure by a few seconds. The convulsion consisted of the utterance of a sharp cry, then unconsciousness, falling and clonic jerks of all limbs lasting but a few seconds. During electrocardiographic recording the pain was reproduced by stimulation of the left tonsil which was accompanied by bradycardia, then cardiac arrest with convulsion. Mechanical stimulation of the carotid sinus in this patient had no effect. On stimulation of the IXth nerve at operation, Dr. H. G. Schwartz elicited pain in the throat radiating to the ear, and on stimulation of the rostral vagal rootlets pain was referred to the ear which the patient said was not the same as her original pain. These two most rostral rootlets of the vagus as well as the glossopharyngeal fibres were divided with complete relief of all symptoms. Harris also (1926, p. 328) reports a patient whose epileptic fits were preceded by spasms of right-sided glossopharyngeal pain. This does not mean that all cases of so-called carotid sinus epilepsy are actually a form of glossopharyngeal neuralgia. White, Smithwick and Simeone (1952, p. 234) have reported in detail

three of the four patients from this hospital in whom the seizures were *brought on by pressure over the carotid bifurcation with no accompanying* neuralgia, all of whom were effectively relieved by denervation of the carotid sinus.

One of our own patients illustrates not only the syndrome of the irritable carotid sinus associated with glossopharyngeal neuralgia, but is also another example of the unreliability of the patient's responses in determining the extent of rhizotomy required:

M.P. (M.G.H. #759485), a 52-year-old male, gave a history of onset eight years before admission of paroxysms of pain referred to his right ear. Each pain lasted a few seconds and he would have one to two attacks per day over periods of a week or more. These cycles recurred every few months with the exception of two long intervals of freedom, one for a year and the other for eight months. Twenty months before entry the attacks of pain became more severe, lasting from 5 to 20 seconds, and there would be 40 to 60 attacks per day. The pain was "hot, stinging," rapidly reached a climax and then gradually subsided. It was now referred over a wider area to the mastoid, temple above the zygoma, and halfway down the ramus of the mandible. Talking and swallowing, at times even a light touch against the pinna, tended to bring on a paroxysm. In the past few weeks he had observed that the right side of his tongue and palate had a constant "numb, burning feeling," and there was a steady dull pain in the region of the right temporo-mandibular joint. He had lost consciousness in some of his most severe attacks. His wife knew of five such episodes in which, while swallowing food at the table, he was seized by an unusually intense pain, then "flopped" unconscious either forward onto the table or from his chair to the floor. His eyes were seen to roll upward in some attacks, but he had no jerking of limbs or face, no tongue biting and no incontinence. He would regain consciousness in a few seconds and remain confused and disoriented for a minute or two.

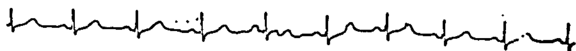
Pressure over the right coronoid notch or over the upper pole of the right tonsil provoked a typical outburst of pain. No paroxysm ensued on rubbing inside the external auditory canal or on the ear. With the aid of Dr. Gordon Myers the following studies were carried out. Neither pain nor any other subjective symptom or sign was produced by protracted vigorous massage in the region of either carotid sinus. An electrocardiogram during such massage also showed no change, but five successive periods of brief digital massage in the right tonsillar fossa caused a burst of pain lasting 5-15 seconds with marked slowing of the heart. This coincided precisely with the duration of his pain (Fig. 118). The electrocardiographer could tell at once by the abrupt changes in heart rate exactly when the pain began and when it ended. Three successive doses of atropine sulphate were given intravenously until a total of 5 mg. had been injected. Following the first two doses the bradycardia during an attack of pain was not so marked and it was eliminated after the third dose. The pulse rate then remained at about 118 before,

during and after one of the most severe of the induced attacks. Presumably only the vagal efferent pathway of the carotid sinus reflex was inhibited by the atropine. The patient had no symptoms such as syncope, mental confusion or convulsion as a consequence of the induced attacks, but he volunteered that the pain in them was not nearly as severe as during the attacks in which he fainted. Severe pain induced by such measures as compression of an Achilles tendon had no effect on the pulse rate or electrocardiogram. We propose to carry out similar studies in other cases of glossopharyngeal neuralgia to see if this curious overflow from one afferent pathway concerned

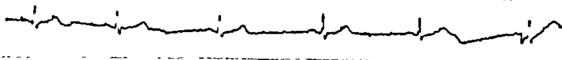
M.P.-M.G.H. #759485

ELECTROCARDIOGRAM DURING
AND BETWEEN PAROXYSMS OF PAIN

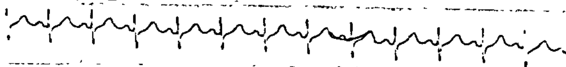
RESTING PULSE RATE 80/MIN



DURING PROVOKED PAROXYSM OF PAIN
PULSE RATE 51/MIN.



RESTING PULSE RATE AFTER 5 MG.
ATROPINE SULPHATE I.V. 118/MIN.



DURING PROVOKED PAROXYSM OF PAIN.
PULSE RATE UNCHANGED AT 116/MIN.

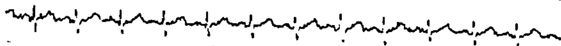


Fig. 118 Electrocardiogram of Patient M. P. (page 488) during and between paroxysms of pain of glossopharyngeal neuralgia, associated with accompanying vagal bradycardia.

with pain into another functionally unrelated contiguous afferent system occurs routinely. We consider this a remarkable phenomenon in the nervous system of "failure of insulation" of one component from its neighbour, unexplained by injury from trauma or known organic disease in the manner demonstrated by Granit, Leksell and Skoglund (1944).

Application of 10 per cent cocaine to the right tonsillar fossa eliminated the attacks of pain for some hours. Accordingly on 12/5/51 the nerves in the right cerebellopontine angle were exposed under local anaesthesia in this unusually placid and cooperative man. Stimulation at 0.01 volt as well as a touch with special pointed bipolar electrodes applied to the glossopharyngeal nerve caused pain in the ear like that occurring clinically. Such stimuli 1) to the upper (vestibular) component of VIII caused vertigo; 2) to the lower (cochlear) part of VIII caused a roaring in his ear; and 3) to the VIIth nerve caused facial twitching. The nervus intermedius was not identified when VIII was elevated, but a dull nerve hook run mediolaterally between VII and VIII caused no pain. The IXth roots were then cut, and reflected well away from the vagus. The rostral filament of X was next separated from the rest of the tissue by an insulating strip of rubber tissue. A touch of the pointed electrodes also evoked pain like that experienced in the clinical attacks, so that rootlet was divided. The next one down, a substantial strand, was isolated in like fashion and upon similar stimulation also yielded similar complaint of pain. Division of this rootlet, which left perhaps 3/5 of the total nerve intact, was followed by a striking change in his voice which became hoarse and high pitched. However the next vagal rootlet was isolated on a rubber tissue and stimulated by light touch of the electrodes. The pain which now ensued was referred just below the ear, but the patient insisted that he had also had this type in his clinical attacks. He made these assertions in such a hoarse voice, however, that we decided to leave this rootlet intact. The cut rootlets were reflected well away from this and we think there could have been no spread of stimulus to them. There was no change in the blood pressure upon division of either glossopharyngeal or vagal rootlets.

Postoperatively the patient regurgitated fluids through his nose for three days on attempts to swallow. Thereafter he took his nourishment by mouth with progressively less effort. He was discharged from the hospital shortly and on his seventeenth postoperative day returned for reexamination. Dr. Donald Lewis found that his right vocal cord was still weak, although his hoarseness was nearly gone. On fluoroscopic examination some swallowed barium collected in the right pyriform sinus, which emptied poorly, but no barium went into the trachea. On sensory examination a .5 gram hair felt "a little sharp" on the right tympanum—sharper on the left; a 6 gram point felt nearly as sharp on both the anterior and posterior walls of the right external auditory canal as it did on the left. There was analgesia to 40 gm point in the right tonsillar fossa and both of its pillars, but in the oral pharynx such stimuli usually felt sharp. In the upper nasopharynx Dr. Lewis found that points felt equally sharp on the two sides, whereas in the lower naso-

pharynx they felt equally dull on the two sides. Pinprick applied to the mucosa over the cushion surrounding the right Eustachian orifice was not felt as sharp, but it was sharp behind this cushion. A Eustachian catheter introduced into the orifice caused a sharp "electric-like" sensation. At 13 months postoperatively the pain has not recurred and cannot be provoked, and the hoarseness and dysphagia have disappeared.

This patient illustrates that cephalic pain fibres may travel via numerous vagal rootlets, that these must be divided with caution, and that it is advisable to leave some vagal rootlets intact even though they are transmitting clinically significant pain fibres. Fay (1927) had an early experience which was even more striking on this score. In one of his patients with a carcinoma of the tongue, in whom trigeminal posterior rhizotomy had failed to relieve pain in the ear and throat, he divided all of the left vagal rootlets, leaving the glossopharyngeal intact. The pain disappeared. Appreciation of pinprick and touch was eliminated on the pharynx and the base of the tongue, the external auditory canal, the concha and the base of the scaphoid fossa on the medial surface of the ear. The vocal cord was paralyzed and there was severe dysphagia. After instruction the patient seemed to be able to take fluids slowly without choking or coughing, but on the fourth postoperative day the patient died suddenly from the inhalation of fluid he was trying to swallow.

It is apparent that a variety of clinical pictures may be seen in glossopharyngeal and upper vagal neuralgia, and we have summarized much of the literature because the experience of any one surgeon has been so limited. *In order to secure permanent relief it is often necessary to divide the rostral rootlets of the vagus in addition to the glossopharyngeal.*

C. SUPERIOR LARYNGEAL NEURALGIA

There are several instances described in the foregoing section in which neuralgic pains involved vagal as well as glossopharyngeal rootlets, as proven by recurrence of pain after section of the ninth cranial nerve and subsequent relief upon dividing the upper rootlets of the tenth. The presence of the auricular branch of the vagus to the external auditory canal and pinna has led some surgeons to divide the upper vagal, as well as glossopharyngeal rootlets, whenever neuralgic pains involve the ear, but a few clear-cut cases also show that the superior laryngeal branch of the vagus may carry impulses causing neuralgia. A sparse literature on this subject has ensued since Avellis' (1900) publication drawing attention to patients with a unilateral zone of tenderness just above the larynx associated with attacks of severe pain.

The superior laryngeal branch of the vagus arising from the ganglion

nodosum passes downward medial to the carotid vessels and anastomoses with the pharyngeal plexus of the IXth nerve. It divides at the hyoid bone into an external branch (largely motor) and an internal branch which pierces the midportion of the hyothyroid membrane. This supplies sensory fibres to the epiglottis, base of the tongue and supraglottal portion of the larynx.

Neuralgic pain involving these sensory fibres comes in the usual severe paroxysms. The pain starts in the throat in the general region of the hyoid bone and upper part of the superior thyroid cartilage, but may extend widely up to the zygoma, down to the upper thorax, less often to the shoulder, gums or ear. As in glossopharyngeal-vagal type of neuralgia, swallowing, yawning or coughing may evoke the pain. In particularly severe cases any slight jar of the body, as in walking, may suffice to do so. Talking was the only activity predisposing to an attack mentioned in Harris' case. During the attack the patient may swallow or belch frequently. Tickling or itching sensations may be present in the larynx. Pain is usually produced on examination by stimulating the internal branch of the superior laryngeal nerve either through the skin over the point at which it pierces the hyothyroid membrane or endorally, where it lies in the plica of mucous membrane at the upper edge of the pyriform sinus. The presence of a small zone of external tenderness near the junction of the posterior and middle thirds of the hyothyroid membrane appears to be an important diagnostic feature. In some patients this lies more caudally toward the thyroid cartilage, in others it is more laterally placed at the medial border of the sternocleidomastoid muscle. Injection of the nerve here with procaine or cocainization of the pyriform recess and plica may stop the attack temporarily and thereby demonstrate the offending nerve. Boenninghaus (1906) has described a similar type of neuralgia involving the recurrent laryngeal branch of the vagus; the patients are said to have a tender point inferior to the cricoid cartilage and lateral to the trachea.

Treatment of coexisting tonsillitis or laryngitis is futile. In one patient removal of a pea-sized nodule from the vocal cord on the side of the pain was ineffective. However, Hutter (1929) thought that tonsillectomy may have been related to the onset of attacks in three of his cases; in one of them the operation was an unusually traumatic procedure. He cites two more cases which followed tonsillitis. Harris (1926, p. 335) reported the first patient treated by an alcohol injection of the internal branch of the nerve where it pierces the hyothyroid membrane. Echols and Maxwell (1934) first treated the disorder by operative excision of a portion of the superior laryngeal nerve and Smith, Moersch and Love (1941) added two more successful cases to this type of therapy. In the latter two the attacks of pain persisted postoperatively for three and 11 days before they

stopped. No recurrences have been reported yet following these peripheral neurotomies. If this becomes a problem it would appear logical to expose intracranially the rootlets of the vagus and to cut those whose stimulation evokes the clinical type of pain.

The superior laryngeal branch of the vagus, since it carries the somatic sensory innervation of the larynx and vocal cords, is the nerve primarily concerned with pain in tuberculosis and cancer of these structures. Laryngologists have found it possible to alleviate pain in these conditions by injection of alcohol, according to the method of Labat (1924), or by neurectomy.

CHAPTER XVI

CEPHALIC PAIN—TRANSMISSION PATHWAYS UNCERTAIN

A. AUTONOMIC FACIO-CEPHALALGIA (HORTON'S SYNDROME)

In 1939 Horton, MacLean and Craig described what they considered to be a new syndrome of vascular headache, calling it "erythromelalgia of the head." Two years later Horton reported 72 cases of this disorder; the attacks of pain could be reproduced by subcutaneous injection of histamine, and in 48 of 51 typical cases complete relief of symptoms was obtained for varying periods after "desensitization" by progressively increasing minute doses of histamine. Hence Horton now calls the disorder "histaminic cephalgia." The clinical picture is one of attacks of unilateral pain, constant, burning and severe, involving chiefly the eye and/or temple, often other parts of the face, head and neck. Attacks differ from those of typical migraine in that they: 1) last only a few minutes to a few hours; 2) have a remarkable tendency to occur with clock-like regularity during the daytime but particularly at night, the patient awakening with pains night after night at certain hours; 3) usually have no hereditary background; 4) are rarely accompanied by nausea, vomiting or visual disturbances, 5) are associated with striking manifestations of cranial autonomic activity on the side of the pain. The following are characteristic: both the ipsilateral nostril and the eye water; the conjunctival vessels become injected; the temporal vessels dilate; the nasal mucosa and, at times, the eyelids swell the whole side of the face may flush. 6) In women there is little or no relationship between the menstrual cycle and the bouts of pain. During an attack the reclining position is intolerable, perhaps at least partly because of additional engorgement of the vessels of the head, and the patients may pace the floor. The facial skin on the side of the pain may be a degree or more hotter than that on the other side. Drinking an alcoholic beverage may bring on an attack of pain, but only during the periods when the patient is having attacks.

Once an attack starts the more fortunate patients find that salicylates may abort it. Some patients gain relief by making strong pressure over the eye, the temporal vessels or the common carotid artery, but between attacks there may be marked tenderness over the carotid or its external branches. In only 4 per cent of Horton's cases was the pain bilateral This disorder

is distinguished from trigeminal neuralgia by: 1) extension of the pain outside of the trigeminal zone; 2) the absence of any tendency for external stimuli to provoke attacks; 3) the longer duration and the constancy of the pain, and 4) the localized autonomic activity during attacks. We are impressed by the potential validity of classifying these patients in a separate group.

Examples of this syndrome, as thoroughly described by Horton, have been published earlier in the literature (see Dandy, 1931, case 1) at times under the diagnosis of migraine. A number of Sluder's (1927) patients "with sympathetic signs" and Glaser's (1928) atypical neuralgias with "associated sympathetic phenomena" probably include many in this category. Perhaps priority should go to Vallery-Radot and Blamoutier (1925) who had described one case of the disorder as the "syndrome of hemicephalic vasodilatation." The term autonomic facio-cephalalgia proposed in 1935 by Brickner and Riley is fully descriptive of the symptoms and appropriately noncommittal as to their mechanism. Their three patients differ somewhat from Horton's description in that the attacks of pain in each lasted for a day or more. Wolff (1948, p. 422) gives many reasons for continuing to regard the disease as closely related to true migraine headache and for considering it "one of the many varieties of painful vascular disorders of the head." He has emphasized the importance of nonspecific medical attention, resolution of personal problems, emotional support, rest and reassurance in treatment, as in migraine. Dandy was led to remove the inferior cervical and first thoracic ganglia in his case 1 on account of the autonomic manifestations. These included not only several of those described above, but also ptosis and hyperhidrosis on the painful side of the face with a bradycardia down to 45/min. We should point out, however, that, save for the sweating, these are evidence of parasympathetic overactivity or sympathetic paresis. At the time of his report the patient's relief had lasted only six months and Dandy closed by saying that the treatment was "suggested with the understanding that a greater subsequent burden of proof supported by time and additional patients rests upon the writer." This was never forthcoming. Leriche (1949, p. 345) described a similar patient whose attacks of pain were questionably attributed to a minor head injury two years previously. Over a seven year period the man had had only three or four months free of attacks. Leriche stopped the pain by a stellate block (number of injections and duration of relief not stated).

Case 5 in Horton's series reported earlier by Craig as migraine (1935, case 2) had also had the same type of sympathectomy in 1934, apparently followed by a substantial amelioration of symptoms for about two years. Then as a consequence of bursts of severe attacks he returned to the Mayo

Clinic in 1936 for ligation of his middle meningeal artery, and in 1939 for histamine desensitization. Of 10 clear-cut patients in our own personally observed group, two have had an ipsilateral Horner's sign, one has had persistent ptosis only, one has had miosis during the attacks of pain and another has had a bradycardia during attacks; all of which would suggest that sympathectomy is not likely to help, the more so since intravenous injection of epinephrine may promptly stop an attack. These experiences of Dandy and Horton also illustrate another feature of the disorder, namely, the tendency for protracted periods of spontaneous relief which make it so difficult to assess therapy.

On the basis of the evidence that vasodilation is the cause of this type of headache, Gardner, Stowell and Dutlinger (1947) evolved an eminently rational therapy. They pointed out that Cobb and Finesinger (1932) and Chorobski and Penfield (1932) had found no other efferent pathway of vasodilator fibres to the arteries of the pia mater than the greater superficial petrosal nerve. The latter authors had also assembled the evidence from other sources that the greater superficial petrosal nerve carries secretory

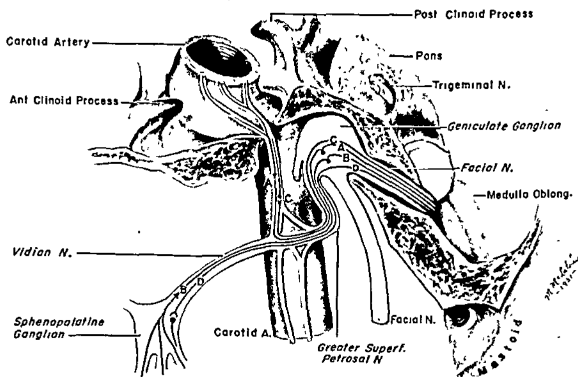


Fig. 119 Afferent and efferent fibres in the greater superficial petrosal nerve.

Afferent impulses may pass, A, from the internal carotid artery and B, from the vidian nerve via the greater superficial petrosal nerve to their cell bodies in the geniculate ganglion and thence to the brain. Efferent vasodilator and secretory fibres pass from the brain through the geniculate ganglion without synapse to terminate around cells: C, on the internal carotid artery or D, in the sphenopalatine ganglion

fibres for the lachrymal gland, as well as secretory and vasodilator fibres for the mucosa of the nose, upper pharynx, soft palate, roof of the mouth and upper lip. The vasodilator fibres in this nerve are preganglionic; those which leave to pass with the vidian nerve undergo synapse with nerve cells in the sphenopalatine ganglion (fibres labelled D in Fig. 119). Chorobski and Penfield present evidence that some fibres pass from the greater superficial petrosal onto the internal carotid artery and its branches, and undergo synapses in the small ganglia which they described on the artery (labelled C in Fig. 119). These fibres traverse without synapse the geniculate ganglion, which is a cell station only for afferent neurones. It seemed likely to Gardner *et al.* that periodic discharges of parasympathetic impulses over one greater superficial petrosal nerve might account for unilateral lacrimation, swelling and secretion of the nasal mucosa and pain in the head, the outstanding symptoms in Horton's neuralgia. They pointed out that unilateral sweating and cutaneous vasodilation are unusual features in these patients, and that in but few of them could the attack be either precipitated by large doses of histamine or relieved by histamine "desensitization." Our experience is in accord with that of Gardner and his collaborators on these scores.

As a consequence of their analysis they suggested the term "petrosal neuralgia" and reported in 1947 the results of dividing the greater superficial petrosal nerve in 13 patients with this disorder. Their results were excellent in 25 per cent, fair to good in 50 per cent and failures in 25 per cent. Regeneration of the cut fibres was shown by return of lacrimation and of pain in some cases; relief of pain and a dry eye again followed redivision of the nerve. This cycle was repeated twice in their case 6. The authors usually noted no recognizable difference between the clinical pictures of the patients who obtained good results and of those who did not. They pointed out that efferent vasodilator impulses, presumably causing headache in the unsuccessful cases, may have arisen outside of the facial-intermedius system, or else peripheral to the point of surgical division. They also suggested the possibility that afferent fibres concerned with pain lie in the greater or lesser superficial petrosal nerves, or along the middle meningeal artery, structures which are divided in the course of their operation.

Studies of Accessory Facial Pain Pathways in Middle Cranial Fossa by Electrical Stimulation

In order to study this problem further we stimulated the nerves of the middle cranial fossa in the course of operations under local anaesthesia for trigeminal, histaminic (petrosal), and atypical facial neuralgia. On the

floor of the middle cranial fossa the greater, lesser, and external superficial petrosal nerves, as well as the middle meningeal artery above the foramen spinosum, were stimulated.

We were able to identify all three nerves (illustrated in Fig. 62) in only one patient. The lesser superficial petrosal nerve passes from the otic ganglion upwards either through the foramen ovale or through its own more posterior tiny aperture, runs antero-laterally across the floor of the middle fossa anterior to the greater superficial petrosal nerve, and enters the petrous portion of the temporal bone to join with the tympanic plexus of the glossopharyngeal nerve in the middle ear. The external superficial petrosal is an autonomic twig connecting the middle meningeal artery with the geniculate ganglion of the facial nerve. Bipolar electrical stimulation was carried out usually with a 1 σ monophasic square wave at 30 cycles/sec. There was great variability from person to person in the presence and type of response, but, in all, pain and movement were exclusively ipsilateral.

a. **Middle meningeal artery, external superficial petrosal nerve and intrapetrous portion of internal carotid artery:**—Stimuli to the middle meningeal artery were applied just above the foramen spinosum. In four patients with Horton's type of neuralgia these caused: in the 1st) at 1.5 volts a sharp stab of pain in a tiny area deep inside the head "where you are working"—no spread. In the 2nd) at 4 volts pain either in the cheek, cheek and eye, lower cheek and jaw, anterior temple just above the zygoma, or in the jaw radiating to the temple. The patient was unable to say whether or not this was like his original pain. In the 3rd) at .5-5 volts pain either in the forehead or above the anterior end of the zygoma; this series of stimuli "brought on the old pain." In the 4th) the external superficial petrosal nerve was clearly seen and the stimuli were applied to the junction of this nerve and the artery; at 3 volts severe retraction of the mouth occurred along with severe pain in the face "like the climax of my attacks." Fay (1932) found that stimulation of the branches of the middle meningeal artery caused severe pain "localized in a general way to the side of the head" on which the stimulation occurred. Stimulus to the main branch of the middle meningeal artery, however, he found caused reference of severe pain deep in the eye. Penfield (1935) has found that pain is referred to the ipsilateral temporal region upon stimulus to the middle meningeal trunk in the general run of patients submitted to craniotomy. The statements of the last three of our patients suggest that this artery and/or its nerves may be responding abnormally and be associated with the attacks of pain. In only one other patient was the external superficial petrosal nerve identified (a case of trigeminal neuralgia). In this individual 3 and 5 v. caused pain in front of the ear without facial movement before the trigeminal rootlets were cut; after these were divided 3 v. caused pain over the ear and 10 v. caused pain in the ear, at times associated with facial twitching. In another patient the bony roof of the carotid canal was virtually absent and this portion of the internal

carotid could be stimulated directly. The results after removal of the greater superficial petrosal nerve overlying it were: at 2 v. pain in the temple; at 4 v. pain in ear and temple, jaw and temple, or under eye and into jaw; at 6 v. pain in the ear. The reference of pain was strikingly similar to that seen on stimulation of the superficial petrosal nerves and the middle meningeal artery.

b. The lesser superficial petrosal nerve:—This was clearly identified four times. In three patients with Horton's neuralgia the responses were: in the 1st) at 12 volts there was contraction of lower facial muscles; at 14 v. the same plus sharp pain in the ear (at this voltage suggesting spread of stimulus to other sensory fibres). In the 2nd) no pain at 2 and 3 v.; at 4 v. pain a) in side of head, b) in front of ear, c) from temple to nose, d) from temple to forehead. In the 3rd) slight facial contraction and trivial pain in the nose at 5 v.; no pain and slight facial contraction at 3 v. In one patient with trigeminal neuralgia in whom the lesser superficial petrosal was clearly seen disappearing into its own little canalis innominatus posterior to the foramen ovale and medial to the foramen spinosum, there was no pain and no facial contraction, even with stimuli up to 20 v. More data are needed.

c. The greater superficial petrosal nerve:—This was stimulated in five patients with Horton's neuralgia. In the first of these a wide variety of parameters, including voltages from 3 to 10, although causing facial contractions consistently, evoked no pain. But in the other four pains were produced at low voltage as follows: In the first of this series pain occurred at 2 v. in front of the ear and in the temple; at 3 v. mild pain over the eyelid or feeling of an electric shock over the temple and middle of the cheek; at 4 v. pain in the ear or in the whole left face with muscular twitching for the first time. After division of the nerve its lateral central end was brought out of its groove to rest on bone anteriorly. Stimulus to the end of the nerve in this new position at 6 v. caused pain under the ear plus twitching of the upper lip. When the nerve was in situ it was not separated from the underlying internal carotid artery by a thin plate of bone as it is normally, and at least some of the responses with the nerve intact were probably due to spread of stimulus to the plexus of nerves on the carotid. In the second patient 2-10 v. always caused pain in the cheek radiating toward the ear and temple, like the original pain but much more severe, no facial contraction. In the third, 3 v. caused "electric shock" in the face with facial contraction; 1 v. caused pain like a clinical attack plus some facial contraction; after the nerve had been divided a 5 v. stimulus to its lateral end (leading to the geniculate ganglion and hence the central end) caused severe pain and facial contraction, whereas the same stimulus to the medial or distal end lying just ventral to the Gasserian ganglion caused a pain different from the clinical pain without facial contraction. In the last patient pain in the jaw or palate was evoked by stimuli of 3 and 5 v. with facial contraction, even at 1 v. an "annoying sensation" in and twitching of the face; cutting

the nerve caused pain in the temple; then 10 v. to the medial distal end of the divided nerve caused no response, whereas 1 v. to the lateral proximal end produced pain in the ear and jaw plus some twitching of the face.

In patients with either trigeminal or atypical facial neuralgia stimulation of the greater superficial petrosal caused no pain in four, even though powerful facial contractions ensued. In the other four patients clear-cut pain occurred related to the stimulated nerve. In two of them the nerve was tested both before and after section of the trigeminal posterior rootlets going to the second and third divisions. That the desired trigeminal fibres were all divided was shown by the appropriate analgesia at postoperative examination. The pain on petrosal stimulation in one of these two was in front of and in the ear, in the other it was referred deep in the face on the stimulated side. The responses were the same before and after trigeminal rhizotomy in each case. In a third patient 20 volts at various points on the Gasserian ganglion after a total trigeminal rhizotomy caused only a sense of twitching of the masticator muscles, whereas 7 v. to the greater superficial petrosal nerve caused severe pain in the eye, nose, cheek and upper gum. These three experiences give evidence that when stimuli to this nerve do cause pain the afferent pathway does not include the trigeminal nerve. In the fourth patient with trigeminal neuralgia 6 v. to the intact greater superficial petrosal caused pain in the ear, upper jaw, nostril or cheek, and cutting the nerve caused a sharp pain in the ear. Ten volts to the medial distal end of the divided nerve then caused no pain. In a final patient operated upon for bullous keratitis 6 v. stimuli to the intact nerve and to its lateral divided end caused severe pain in the temple and cheek, while stimuli to the medial end of the nerve caused only mild pain under the eye along with tearing.

Throughout this series of cases control stimuli to the floor of the skull or to the dura a few millimeters from the nerves were tried and found to cause no pain at voltages from 10 to 60. The tendency for facial contraction to occur even at low voltages when we were stimulating any of the superficial petrosal nerves led us at first to fear that many of our pain responses were due to spread of stimulus to other efferent fibres in the main facial canal. But we also had many positive complaints of pain unassociated with facial contraction, and this plus the absence of pain in a number of patients despite vigorous facial jerks have made us conclude that there are often afferent fibres concerned with pain in the superficial petrosal nerves.

Table XXVII summarizes the salient features of six of our patients who have undergone operation. There were four others who did not require neurectomy. In one of these an alcohol block in the region of the sphenopalatine ganglion has been followed by protracted relief; in the other three the periods of freedom from pain were too long to warrant operation. In all 10 patients the attacks of pain were not provoked by stimuli to the face or head, had a marked tendency to occur at night, and were accompanied by unilateral lacrimation, watering of the nose and reddening of the con-

junctiva. One woman (Mrs. W., see p. 515) with severe migraine was in no wise benefited by section of the greater superficial petrosal nerve.

In summary of the foregoing studies one may say that in four out of five of the patients with Horton's neuralgia, and in five of the other nine with trigeminal or atypical facial neuralgia stimulus to the greater superficial petrosal nerve caused pain localized in the ear, eye or adjoining parts of the head and face. This pain was apparently not caused by vasodilator fibres sending impulses to the periphery which then indirectly set up pain, because after cutting the nerve we evoked it only upon stimulus to the central end. In two of the patients with Horton's neuralgia (H. F. and J. W.) stimuli to the middle meningeal artery also reproduced the pain complained of. These two patients, and a third in whom the characteristic pain was reproduced on stimulation, have had an encouraging degree of clinical relief following operative division of the petrosal nerves, whereas the two patients in whom the clinical type of attack was not evoked have not been helped by this operation. Our data are too fragmentary, however, to permit any final decision concerning the value of neurectomy. They do suggest that the good results are related to interruption of afferent pathways for pain rather than of efferent fibres mediating vasodilation. Figure 119 shows routes of both types of pathway on the basis of the evidence from animals summarized by Chorobski and Penfield (1932), and supported by our sketchy observations in men.

W. J. Gardner (personal communication, 1951) has kindly given us his latest opinion of the value of petrosal neurectomy on the basis of his far greater experience. He is "less and less inclined to resort to resection of the greater superficial petrosal nerve in the treatment of headaches . . . probably the most successful are the typical Horton's type. However, pretty close to half of them do not obtain enough relief to justify the procedure . . . In addition to the immediate failures we find that it is seldom possible to prevent regeneration of the nerve. That this occurs is proven by the return of lachyrmal and nasal secretion, with subsequent abolishment of these functions once more by secondary resection of the nerve . . . We have had just enough undoubted successes to make me hesitate to abandon the procedure completely. We have had patients not relieved of the unilateral headache by ligation of the middle meningeal artery, in whom the subsequent resection of the greater superficial petrosal gave lasting benefit."

In patients deriving clear-cut relief from petrosal neurectomy we propose, upon recurrence of severe pain and resumption of secretion of tears, to investigate the advisability of division of the nervus intermedius. Since the tympanic plexus of glossopharyngeal origin as well as the nervus intermedius, via the geniculate ganglion, both send fibres to the greater superficial petrosal, we propose to stimulate rootlets of both nerves in the

posterior cranial fossa. Those which appear to transmit the clinically significant pain will be cut.

B. PAIN RELATED TO NEOPLASMS OF FACE, HEAD, OR UPPER NECK

The pain which occurs when malignant tumours invade these areas has been difficult for neurosurgeons to treat effectively because such tumours tend to lie deeply in the face, upper neck or ear in zones supplied by many of the sensory branches of cranial and upper cervical nerves. When the pain is confined to the trigeminal field the task is somewhat simpler.

1. Pain in the Face Alone

Grant (1943) has given us an excellent summary of his extensive experiences in this field. He treated 139 patients with cancer about the face by alcohol injection of either the second or third trigeminal division, both of these nerves, or branches of one of them, depending upon the locus of discomfort. Of these, 53 per cent had complete relief, 16 per cent had partial relief and 31 per cent were unrelieved. In the 23 patients in this series who had cancer of the base of the tongue, tonsil or neck, not one was relieved by a third division alcohol injection. In this particular group it is clear that a more extensive procedure should be tried initially. In the patients with neoplasms of sphenoid or maxillary sinuses which may encroach on the pterygopalatine fossa, the second trigeminal division may be displaced in just the area in which the injection is being attempted. Trigeminal operations in his hands gave a much higher percentage of relief than injections. Thus, of 55 patients with cancers about the face treated by intracranial neurectomy of the second and third trigeminal divisions or by rhizotomy of this nerve, the pain was completely relieved in 70 per cent, partially in 9 per cent, and unrelieved in 5 per cent; death occurred in the remaining 16 per cent. Duration of follow-up was not given for any of these patients, nor does he indicate whether the pain recurred in non-anaesthetic zones in the unsatisfactory cases.

In these folks with malignant neoplasms we have tended to proceed directly to operation, confining preliminary injections to those whose pain is unusually circumscribed or who refuse operation. Even so we have been disappointed in the percentage who had relief following our more drastic steps. In a series of 22 patients whose pain seemed wholly within the trigeminal zone and who underwent total or nearly total rhizotomy of this nerve alone, only 50 per cent had good relief of pain for many months or until death. In 24 per cent initial relief was succeeded shortly by progressively more severe recurrence, and another 21 per cent obtained no real

surcease at all. In half of this unsatisfactory 45 per cent pain was referred to zones around the upper face and eye where cutaneous anaesthesia was present. Whether division of the nervus intermedius would help in this group we do not know. Others had their postoperative pain in zones more readily explicable on the basis of overlap from neighbouring nerves. One patient died. Some of the pertinent data is summarized in Table XXVIII.

TABLE XXVIII

TRIGEMINAL RHIZOTOMY FOR RELIEF OF PAIN WITH TUMOURS OF HEAD AND FACE (22 CASES)

Average duration of satisfactory relief to time of death (11 cases)	9 mos.
Average duration of relief when pain recurred before death (10 cases)	1 mo
Recurrence of pain in operated trigeminal zone	7 cases
Recurrence of pain outside operated trigeminal zone	at least 2 cases
Postoperative mortality	1 case

2. Pain in the Back of the Lower Jaw or Mouth; in the Throat or Ear

a) Multiple rhizotomies:—When the pain is in these regions more nerves must be cut. Fay (1926) was an early proposer of multiple rhizotomies in the posterior fossa and upper neck. His patient was relieved of pain over the mastoid area and on swallowing by glossopharyngeal and upper cervical posterior rhizotomy on one side. As soon as Dandy (1929B) had perfected his "subcerebellar" approach to the fifth nerve, he promptly used it for a combined section of fifth, ninth and if necessary of upper cervical posterior roots as well, reporting his first four cases in 1929. Grant (1943) has had a gratifying experience with combined section of the fifth and ninth nerves in these patients. Only two of 15 died and the other 13 were relieved of their pain. Cancerous pain referred deep in the ear has been an especially difficult problem. Grant (1943) has had three failures in this category. He mentioned one such patient in whom even rhizotomy of the fifth, seventh, eighth, ninth and twelfth cranial nerves and of the upper three cervical posterior roots gave no relief. From the experiences described under glossopharyngeal and upper vagal neuralgia, it seems likely that the upper fibres of the tenth nerve were responsible for the residual pain.

Our own long term results in a series of 14 cases who had some combination of trigeminal, glossopharyngeal and upper vagal rhizotomy, often with posterior cervical rhizotomy, were astonishingly discouraging. Relief lasting six months occurred in only two patients; in one of these death supervened within a few weeks of recurrence of pain, in the other a unilateral lobotomy 10 months after the first operation stopped the reappear-

ing pain for the remaining six weeks of the patient's life. In five more patients there was also a period of initial relief, but it was shorter; two patients were not relieved at all, another four died before leaving the hospital, and in one a senile psychosis made it difficult to evaluate the degree of relief. Not only in the four patients who died, but also in others we have had so much trouble maintaining a clear airway that we now do a tracheotomy before operating in the posterior fossa for pain from a lesion which may embarrass the airway. We also find that these patients are usually too ill to tolerate the sitting position for operation and we carry it out in lateral recumbency with the head elevated (Fig. 66C).

In at least four of the patients who had rhizotomy of the fifth, ninth, the upper part of the tenth and the upper cervical posterior roots, some portion of the external auditory canal was not anaesthetic and there was still pain deep in the ear or throat. Accordingly we have added section of the nervus intermedius to this operation in one more patient operated in 1949 with a satisfactory degree of relief of pain until death six months postoperatively.

In a similar situation our associate, Dr. Hannibal Hamlin, has divided these roots plus all of the seventh and eighth. The complete relief of pain in this patient lasted for less than five months, but much of the trigeminal skin was not anaesthetic. Schwartz (1950) also reported a patient in whom section of part of the fifth and tenth and all of the ninth left residual pain. At a second operation the remainder of the fifth, the nervus intermedius, and the upper cervical posterior roots were cut. This helped greatly; only slight residual pain remained in the ear. *Our experience certainly substantiates the view that rhizotomy including all possible cephalocervical pain fibres is essential for sustained relief in these vexatious problems.*

b) **Trigeminal tractotomy:**—Weinberger and Grant (1942) were the first to report a significant series of trigeminal tractotomies for patients with pain from tumours. In their nine surviving patients followed from 17 days to 15 months, there was incomplete relief of pain in only three patients. This was accounted for in one patient (their case 15) by failure to obtain significant sensory loss, and in the other two with complete trigeminal analgesia (cases 11 and 16) they thought the pain was due to lesions outside the trigeminal zone. Before it was realized that other facial pain pathways enter the descending trigeminal tract, they also stated that rhizotomy of the ninth was often necessary (Grant and Weinberger, 1941B) in addition to cervical posterior rhizotomy.

In the three patients we operated on from 1940 to 1942 with incisions designed to cut only the descending tract, there was hypalgesia in the facial skin in one, analgesia faded to hypalgesia in eight days in a second;

in the third no late examination of sensation was carried out, but the pain recurred in two months. Although Hamby, Shinners and Marsh (1948) did 13 bulbar tractotomies along with cervical rhizotomy for this type of pain, their principal comment on this group was that they had a mortality rate of 46 per cent. Half of their deaths occurred within a few days of operation, principally from aspiration pneumonia. We too have found that the large, often ulcerating masses in the mouth and pharynx present a major hazard to the patient's airway and, in order to lower our excessive mortality of 36 per cent, we are now carrying out a preliminary tracheotomy in a new series of these procedures which we have started.

Sjöqvist's tractotomies in three patients with malignant tumours of the face and neck all gave satisfactory relief of the pain. We have had a contrary and surprisingly disappointing experience. When we first noted in 1943 that the other cephalic pain pathways joined the descending trigeminal tract, we anticipated that our broad section including and extending beyond this tract would be an ideal solution for this type of problem. With this in mind we carried out a series of 10 operations from 1943 to 1946 in which this type of bulbar tractotomy was done usually combined with upper cervical posterior rhizotomy. Of the six survivors only one has had long term relief of pain. In him the trigeminal tract was not incised as planned because the initial insertion of the knife blade at the emergent eleventh rootlet started an arterial haemorrhage from the ventral aspect of the bulb, and the wound was closed once the bleeding was stopped. His cervical posterior rhizotomy apparently sufficed. Of the other five patients three (Dorothy G., Norman G. and Antonio O.) showed some recession of analgesia. But in all three and in the other two patients as well (William G. and Edward P.), although analgesia persisted around the forehead and eye, this was one of the chief areas of reference of pain when it recurred within a few days to two months after operation. Figure 120, taken from the postmortem on Norman G. four months after operation, shows complete degeneration of all fibres in the descending trigeminal tract below the level of incision. This finding is evidence that some pain fibres travelling in nerves V, VII, IX and X may terminate rostral to the obex, the level at which incision was made in this patient.

In two of these patients a trigeminal rhizotomy was then performed. In patient William G. stimulation of the central end of the posterior root divided in the middle cranial fossa caused severe pain usually referred to nose or cheek, whereas 140 volts to the distal end or to the ganglion was painless. This led us to hope that some fibres not responding to pinprick were active in the trigeminal nerve and transmitting pain. However, in both this patient and Antonio O. the total trigeminal rhizotomy was followed by worsening of the pain in the face, even though complete tri-



Fig. 120. Complete degeneration of spinal tract of trigeminal nerve caudal to bulbar incision

Area of degeneration is enclosed in dotted lines. Patient Norman G (Table XXVI, Case 24) Postmortem four months after tractotomy at level of obex.

[illegible] ed the analgesia and thermanaesthesia produced [illegible] this grossly unsatisfactory group of experiences we gave up tractotomy at or below the obex for this type of patient. We do not as yet have a satisfactory explanation for these numerous failures following tractotomy and following multiple posterior rhizotomies which seem to yield the desired analgesia or anaesthesia. We have now embarked on a series of bulbar tractotomies with incisions rostral to the obex in the hope of obtaining a more extensive analgesia of all cephalic structures and a better relief of pain.

When the pain is bilateral the task of achieving relief by multiple rhizotomies is even more formidable. Wycis (1945) has relieved bilateral pain in the neck and in the throat radiating to both ears by dividing bilaterally the glossopharyngeal and first to fourth cervical posterior roots. This was perhaps a lucky outcome since the patient still felt pain as a prick in the auditory canals and ear drums. The patient died in a month because the sloughing carcinomatous epipharyngeal mass facilitated development of aspiration bronchopneumonia; this might have been avoided by a tracheotomy. Another interesting complication of the bilateral glossopharyngeal section was a persistent vascular hypertension.

We have had so much trouble relieving unilateral pain in this region by rhizotomies that we proceed at once to lobotomy if it is bilateral. Scarff's (1950) complete unilateral prefrontal lobotomy has given good results in nine of 11 patients with pain from tumours in this area. Six of these unfortunates maintained their relief until death one to three-and-a-half months postoperatively. Relief persisted in the other three at two to nine months after operation. Of the two patients in whom relief was not satisfactory, one still had intolerable pain unrelieved by drugs even after the lobotomy had been made bilateral. Krayenbühl and Stoll (1950A) record another complete failure of unilateral lobotomy to relieve pain from a carcinoma metastatic to the base of the skull. In Campbell and Whitfield's (1950) case 7 a bilateral lobotomy gave good relief of pain in the carcinomatous lower jaw, lasting for the remaining four months of the patient's life, but he was combative and fearful during this period. For our results with lobotomy see Chapter X.

C. POST-TRAUMATIC PAIN IN THE HEAD AND NECK

We are describing as a separate small group those patients whose cervical, cephalic or facial pain appears to follow upon local trauma either from external violence or local infection with subsequent surgery. We find that our neurosurgical efforts to relieve these pains are more fruitful than in the atypical neuralgias of this area. This observation has been but little



Fig. 120. Complete degeneration of spinal tract of trigeminal nerve caudal to bulbar incision.

Area of degeneration is enclosed in dotted lines. Patient Norman G. (Table XXVI, Case 24). Postmortem four months after tractotomy at level of obex.

temple and orbit, especially on electrical stimulation of C3. After five months this patient's occipitofacial neuralgia is effectively relieved, although she still complains of some neck and shoulder pain due to a diffuse cervical arthritis.

2. Cephalic Neuralgia Secondary to Facio-cephalic Injury

The pertinent details in six of our eight cases with this type of post-traumatic neuralgia are summarized in Table XXIX. In the first three patients the pain was clearly in the upper trigeminal area. Despite the discouraging *presence of a continuous aching component in two of them*, neurectomies at the eyebrow have given relief which continues long after recovery of sensation in the forehead. In these patients a vicious mechanism of irritation was broken merely by temporary denervation; both had had their pain too long to permit the assumption that it could have cleared up spontaneously in the interim of denervation that follows peripheral neurectomy. Edward C. G. (M.G.H. #220190), on the other hand, required a subsequent trigeminal rhizotomy and even had to have this repeated when partial return of sensation occurred. In the next three patients the lesion bordered on the ear. George K.'s pain in the temple may well have been due to irritation of both the great auricular branch of the cervical plexus and auriculo-temporal branch of the trigeminal, since denervation at both sites was required for relief. In Theresa S. and Florence W. pain was situated at almost exactly the same spot behind the ear and followed infection and several mastoidectomies in each. But in the former patient cervical posterior rhizotomy gave a useful degree of lasting relief after procaine blocks of the cervical plexus and superficial cervical plexectomy gave encouraging, though temporary, results. For three years we were especially pleased at the result in Florence W. Her incapacitating pain was referred just a little deeper than that of the previous patient, was unaffected by cervical procaine block. A perfect result was maintained for three years after division of nervus intermedius, VIIIth, IXth and rostral portion of Xth nerves. At the time of correcting the proof, we

emphasized previously. Leriche (1949, p. 344) mentions under this heading a single patient with pain in the upper lip and cheek coming on four years after laceration here. Four procaine blocks around the stellate ganglion and external maxillary artery yielded a nine month remission from pain.

I. Cephalic Neuralgia Secondary to Injury of Upper Cervical Nerves

Hunter and Mayfield (1949) have presented a neat anatomical demonstration that the second cervical nerve is peculiarly subject to injury if the head is abruptly rotated. In eight persons traumatized by such a twist of the head, the following clinical picture ensued. These patients tended to have a more or less constant discomfort in the suboccipital region on the side involved; superimposed on this were attacks of pain which began in this region and radiated to vertex, temple or orbit, less often to the ear or the entire head. The attacks resembled Horton's syndrome in that they were likely to be nocturnal and to be associated with facial flushing, epiphora and nasal obstruction on the side involved. On examination there was tenderness over the point of emergence of the C2 root and the course of the greater occipital nerve, which was much more pronounced during an attack of pain. Hyperextension of the neck or rotation of the occiput to the painful side usually produced the pain, and procainization of the second cervical nerve root stopped it abruptly; this was also achieved, but less effectively, by block of the greater occipital nerve. All eight patients were "relieved or greatly benefitted by interruption of the upper cervical nerves." In a later presentation, Mayfield and Hunter (1952) report on 20 cases of C2 posterior rhizotomy and on three more with division of C2 and C3 posterior roots. In 11 of these, just under half, the patient has remained without any pain. In many of the 23 there was no prior trauma, and in this subgroup without trauma the results were poor. The more minor procedure of avulsion of the greater occipital nerve, carried out in 10 other patients, has been followed by recurrence of pain. Raaf (1948) has reported two patients who, following avulsion of a greater occipital nerve, had persistent symptoms of damage to the spinal cord. These were minor in one patient but serious in the other. There seems to be little excuse for avulsing this nerve. If a temporary measure is to be used, excision of a segment of the nerve is clearly preferable.

We have had experience with two cases in this category. In the first patient (Mary W., MGH U-511841) a C2-3 posterior rhizotomy yielded the appropriate anaesthesia but no significant relief of pain, although the onset was clearly related to injury. In the second (Dorothy M., MGH U-745590), following temporary relief by diagnostic xylocaine block, exposure and stimulation of C2-3 posterior roots reproduced the pain in the region of the

George K. M.G.H. #558560	36	Drainage L. parotid abscess—incision in front of ear 1941.	In 1944 onset constant, dull ache in L. temple, with sharp severe pains superimposed here and lasting 5 min. to 2 hrs.	Excision local scar 3 times by Dr. C. Mixter.	1945 and 1946	
				L. upper cervical plexectomy.	1.46	Numbness upper neck and posterior scalp, but only brief period of relief.
				L. trigeminal 3rd division alcohol injection with spread to ganglion.	12.31.46.	Relief for only 36 hours, although anaesthesia throughout 3rd division 4 years later.
				Repeat L. upper cervical plexectomy after stimulation proximal neuroma in neck reproduced pain in L. temple, Dr. W. J. Mixter.	5.3.49.	Virtually complete relief persists at 3¾ yrs.
Florence W. M.G.H. #632111	35	Many abscesses R. ear in childhood. April '47 R. radical mastoidectomy—ear discharging for 6 mos. July '47 R complete radical mastoidectomy. Jan. and Aug. '48 revision of R. mastoid cavity. Dr. C. Johnson.	Since '47 severe pain over lower part of anterior border of R. mastoid process, referred about 1 cm. deep to skin, often wakes pt. out of sound sleep; may disappear for weeks to months; tends to recur after coryza, no relief from codeine.	*Procaine* block C2-3 and cervical plexus.	11.29.49.	Anaesthesia upper neck and posterior scalp but no relief of pain.
				Rhizotomy n. intermedius, VIII, IX, and rostral filaments of X.	12.5.49.	Anaesthesia of nearly all of mastoid cavity, epitympanum and oral pharynx. Complete relief of pain at 3 years but partial recurrence at 4 years.
				Bulbar trigeminal tractotomy	4/20/51	Again relieved at 6 mos.

TABLE XXIX

POST-TRAUMATIC PAIN IN THE HEAD AND NECK

Name	*Age*	*Injury*	*Pain*	*Operation*	*Date*	*Result*
Dorothy G. M.G.H. #2408	39	L. frontal sinusitis, osteomyelitis, and cerebral abscess with treatment in 1932 including extensive removal of frontal bone.	Aching or sharp stabbing pains L. forehead intermittently since 1932. Since May 1949 sharp pains much oftener, brought on by touching infero-lateral margin of frontal defect.	L supraorbital, supratrochlear neurectomy	8.24 49.	Original anaesthesia of L. ant. quadrant scalp post-op. faded at 4 mos., nearly gone at 13 mos. Complete relief of pain at 13 months.
Edward C. G. M.G.H. #220190	32	Laceration R. frontal scalp late in 1936.	Attacks began in forehead as dull paraesthesia, gradually becoming extremely severe pain, then slowly fading out: start in R. medial forehead, then radiate to R. eyeball, frequency 2-3x/day; duration 20 mins. to 3 hrs.; many attacks at night, no relief from morphine.	R. supraorbital neurectomy	6.18.40.	No anaesthesia medial forehead and pain recurred here.
				R. supraorbital and supratrochlear neurectomy.	11.23.40.	Relief while anaesthesia lasted.
				R. trigeminal rhizotomy, Dr. Hodgson.	2.12 41.	Anaesthesia whole R. face; pains continued for 2 weeks then stopped for 2½ yrs.; by that time some recovery of sensation in first 2 divisions and pain recurred.
				R. trigeminal rhizotomy, Dr. Poppen.	11.43.	Again pain free for 4 yrs. with anaesthesia R. face; then developed attacks of pain same type L. forehead and eye.
Thomas K. M.G.H. #36680	39	In 1939 a blow fractured skull just above L. orbital ridge, with laceration in eyebrow.	Severe lancinating pain L. lower forehead till 3 months after injury, then intermittent dull ache worse on fatigue or eye-strain.	L. supraorbital neurectomy	8.21.42.	Complete relief of pain persists 8 years later.
Theresa S. M.G.H. #533662	52	L. otitis media and mastoiditis; 2 mastoidectomies Jan. '46 with 6-8 weeks drainage thereafter. Picture complicated by much tension and anxiety; many psychiatric interviews; essential hypertension.	Right after 2nd operation a constant dull post-auricular pain with acute exacerbations lasting 2 hours to 2 days; associated with vertigo and nausea; unrelieved by codeine.	Procaine block to mastoid scar and cervical plexus.	7.46	Relief about 6 weeks.
				Repeat procaine block.	1.47	Brief relief.
				Neurectomy L. lesser occipital and great auricular nerves.	3.11.47.	Relief 4½ mos. till anaesthesia over painful area receded.
				Post. rhizotomy L. C1-C4	12.8.48.	Nearly complete relief at 21 months, then partial return of pain but no analgesics being used. Anaesthesia post. head and entire neck.

George K. M.G.H. #558560	*36*	*Drainage L. parotid abscess—incision in front of ear 1941.*	*In 1941 onset constant,* dull ache in L. temple, with sharp severe pains superimposed here and lasting 5 min. to 2 hrs.	*Excision local scar* 3 times by Dr. C. Mixter.	*1945 and 1946*	
				L. upper cervical plexectomy.	1.46	Numbness upper neck and posterior scalp, but only brief period of relief.
				L. trigeminal 3rd division alcohol injection with spread to ganglion.	12.31.46.	Relief for only 36 hours, although anaesthesia throughout 3rd division 4 years later.
				Repeat L. upper cervical plexectomy after stimulation proximal neuroma in neck reproduced pain in L. temple, Dr. W. J. Mixter.	5.3.49.	Virtually complete relief persists at 3½ yrs.
Florence W. M.G.H. #632111	35	Many abscesses R. ear in childhood. April '47 R. radical mastoidectomy—ear discharging for 6 mos. July '47 R. complete radical mastoidectomy. Jan and Aug. '48 revision of R. mastoid cavity. Dr. C. Johnson.	Since '47 severe pain over lower part of anterior border of R. mastoid process; referred about 1 cm. deep to skin, often wakes pt. out of sound sleep, may disappear for weeks to months, tends to recur *after coryza; no relief from* codeine.	Procaine block C2-3 and cervical plexus.	11.29.49	Anaesthesia upper neck and posterior scalp but no relief of pain.
				Rhizotomy n. intermedius, VIII, IX, and rostral filaments of X.	12.5.49	Anaesthesia of nearly all of mastoid cavity, epitympanum and oral pharynx. Complete relief of pain at 3 years but partial recurrence at 4 years.
				Bulbar trigeminal tractotomy	*4.20.51*	*Again relieved at 6 mos.*

geminal analgesia at operation, but this analgesia soon faded and the pain returned. We have not subsequently determined whether an effective trigeminal denervation would stop the pain. Trigeminal rhizotomies were carried out on this patient by Drs. White, Mixter and Poppen, but were never successful in securing complete sensory denervation.

To our one failure in the eight cases described above should be added another, Susan G., described on page 436. This still leaves us with a much more satisfactory score than we have for the general group of atypical facial neuralgias. We recommend a thorough trial of local denervation in patients whose continuing pain may be related to local injury.

a) **Itching:**—Another type of chronic facial discomfort, itching, is illustrated by our patient Edward G. This man (case 16, Table XXVI) began to have intense itching in the front part of his scalp on the left side 15½ years after a compound fracture of the skull, which was complicated by osteomyelitis of the underlying frontal bone. This sensation caused the patient to scratch not only all the hair off the left eyebrow and anterior quadrant of the scalp, but also portions of the skin, leaving deep pitted scars and sores. The itching stopped for six weeks after supraorbital and supratrochlear neurectomy; it then recurred only in the area of returning sensation at and above the eyebrow. He promptly scratched out his regrowing eyebrow but left *in situ* the returning hair further back in the anaesthetic area. The skin and underlying tissues down to the bone were re-divided over the length of the eyebrow five months later, a procedure which again stopped the itching above the incision, but left him with itching in the left upper and lower eyelids and nose. He also had brief paroxysms of pain 24-48 times a day, referred to the left eyebrow and forehead, which might even awaken him from sleep. An extensive bulbar tractotomy stopped virtually all of his facial pain and itching at the price of no significant neurological sequel, and this result was maintained at our last report four years postoperatively. We know of no similar case recorded in the literature.

D. MIGRAINE

The most striking feature of the migraine syndrome is recurrent headaches. Since pain is the only aspect with which this book is concerned, we need not discuss the other clinical aspects of the disorder. Graham has characterized migraine in a phrase as "familial, periodic, sick headache with a vascular component." The headache is typically a one-sided hemicrania. At times, however, it is bilateral or shifts from one side to the other. Surgical intervention, not a simple matter at best, then becomes a very difficult problem. The overwhelming majority of these patients are treated so well by physicians that surgical measures are superfluous.

A formidable body of evidence has accumulated which indicates that the headache of migraine is produced mainly by the dilation of arteries to the head, and is relieved when these vessels return toward normal calibre. For a good summary of this proof see Wolff (1948, pp. 265-288). Hence surgical treatment of this type of pain may be directed toward: 1) prevention of arterial distension by proximal occlusion of arteries or by division of vasodilator nerves, 2) alternatively, the cutting of the afferent fibres transmitting pain impulses from the dilated vessels to the sentient areas of the brain.

1. Prevention of Arterial Distension

a) **By arterial occlusion:**—The simplest way to reduce arterial dilation is to ligate the artery. In fact, percutaneous occlusion of a carotid in the neck or of its branches in the scalp often reduces or interrupts pain. Consequently division of the external carotid trunk, or of branches such as the middle meningeal artery at the foramen spinosum, or the superficial temporal artery, has frequently been tried. But even in those in whom a measure of success is achieved, the good result may be only temporary because pain is likely to return with the enlargement of collateral channels, and the regeneration of periarterial nerve fibres which may have been active in the disorder.

Ambroise Paré (cited by Leriche, 1949, p. 152) provided one of the earliest reports. Having benefited his own migraine by division of the superficial temporal artery between ligatures, he used the same treatment for this disorder in the Prince de la Roche-sur-Yon. Massart and Leriche (cited by Leriche, 1949, p. 153) have each had a successful result in a patient with migraine treated in this fashion. Leriche's patient, three years after bilateral superficial temporal arteriectomy, was having only attacks of nausea in place of the pain.

Any encouragement from the report of Dickerson (1933) on relief of migraine in seven cases by ligation of the middle meningeal artery is tempered by the shortness of his follow-up (two years maximum) and the absence of further accounts by him. Immediate failure from this procedure is recorded by Craig (1935, case 1) and by Olivecrona in five of his six cases (1947A). Gardner (personal communication, 1951) has also been dissatisfied with this operation for unilateral headache. Of course division of an artery interrupts any sensory or vasomotor fibres on its adventitia, so this procedure has neurological as well as mechanical consequences. Rowbotham (1949) mentions two patients in whom removal of a length of superficial temporal vessels failed to give any relief. In one of these patients subsequent excision of supraorbital and middle meningeal arteries

TABLE XXX

MIGRAINE

Cases	*Clinical Features*	*Operation*	*Date*	*Result*
1. Ida H. 25 yrs. M.G.H. #79267	L. parietal pain; nausea; brief periods mental confusion, epileptic attacks until 1935.	Division L. middle meningeal artery	7.29.38.	No relief.
2. Ruth O. 38 yrs. M.G.H. #240555	L. occipital to frontal pain; severe; duration 3 hours to 3 days, nausea and vomiting once only.	Division L. ext., carotid artery.	5.27.41.	Severe pain gone for 5 years; then less severe attacks recurred but relieved by gynergen-caffeine suppositories for next 5 years.
3. Bertha P. 27 yrs. M.G.H. #226991	Attacks exclusively R.-sided.	Division R. ext. carotid artery.	11.28.41.	No pains for 9 months; then severe recurrence.
4. Katherine R. 52 yrs. M.G.H. #516388	For 26 years R. frontotemporal headaches. Attacks lasting hours to days with nausea and tenderness above zygoma "almost to the middle of head". Spent much of adult life in doctors' offices or hospitals for relief of this pain.	Procaine block R. Gasserian ganglion (Dr. Joseph Evans).	1915.	Anaesthesia R. face and tongue but no relief during attack.
		Procaine block R. sup. temporal artery and auriculo-temporal n.	1.21.46.	Tenderness and pain persisted.
		Procaine block R. supraorbital n.	2.5.46.	No relief during attack.
		Division R. mid. meningeal and sup. temporal art. and auriculo-temporal n. Dr. Mixter.	7.2.46.	Complete relief for 6¼ yrs. to present.
5. Edward McF. 28 yrs. M.G.H. #538544	Attacks severe steady pain over area 3 cm. in diameter at L. fronto-temporal junction. Sometimes helped by ergotamine tartrate, but not in severe attacks lasting 2-3 weeks.	L. stellate alcohol injection.	8.16.46.	Horner's sign; no relief.
		L. supraorbital neurectomy.	8.19.46.	Anaesthesia forehead; relief of pains for 19 months.
		Division L. sup. temporal artery.	3.20.48.	Almost complete relief of pains maintained at 58 mos. with the aid of Dr. John Graham's medical regime.
6. John B. 46 yrs. M.G.H. #206356	Attacks headache many years, chiefly R. sided; longest spontaneous relief 6 mos., this many years ago. In recent mos. pain 1/3 to 1/2 the time.	Division R. supraorbital, sup. temporal and occipital art.	7.20.48.	Immediate marked reduction in headaches since last operation; >90% relief maintained at 52 mos. with aid of Dr. John Graham's medical regime; infrequent headaches brief and mild.
		Division R. mid. meningeal art.	9.8.48	
		Division R. ext. carotid art.	9.22.48.	
		Division L. ext. carotid art	9.27.48.	

7. Katherine F. 42 yrs. M.G.H. #51565	For 15 years R. hemicranial headaches in attacks lasting hours, followed by L. fronto-temporo-facial ache of 3-day duration. *Headache stopped by* ergotamine tartrate.	R. cervical sympathectomy. Division R. ext. carotid art. *Periarterial stripping ext., int.* and common carotids. Traction on R. int. or ext. carotid started R. migrainous pain.	11.2.49.	No relief.
8. Helen W. 28 yrs. M.G.H. #559401	R-sided headaches, radiating at times to L., for 9 years; relieved at first by ergotamine tartrate, later 340 mg./month gave in-*adequate relief*, because of unusual tolerance to drug.	Division R. ext. carotid art.	1.13.47.	Brief relief.
		Division L. ext. carotid art.	2.19.47.	Brief relief.
		Division R mid. meningeal art. and sup. petrosal n.	9.11.47.	No relief.
		R partial V rhizotomy.	12.18.47.	Anaesthesia lower face; no relief.
		R total V rhizotomy.	12.23.47.	Anaesthesia entire R. face. Complete relief for 5 yrs. to present.
9. Margaret J. 26 yrs. M.G.H. #192137	Attacks R. fronto-parietal pain *radiating to L. side and pos*teriorly, lasting a few hours to 3 weeks, relieved by pressure over R. carotid or R. temple, no relief from ergotamine tartrate, migraine in 2 close relatives.	Division R sup. temporal art.	10.18.39.	No relief.
		R. *supraorbital neurectomy.*	8 41.	Anaesthesia R. forehead, relief for 12 weeks.
		Procaine block, R stellate ganglion.	2.6.42.	Horner's sign, hot hand, no relief.
		Procaine block R. Gasserian ganglion. Dr. Michelsen.	2.6 42.	Anaesthesia R. face, temporary *relief* as soon as 1st and 2nd divisions became anaesthetic; this lasted 30 *mins.*
		R. trigeminal rhizotomy Dr. Mixter.	2.20.42.	Anaesthesia R face, immediate and complete relief of pain for 10 years; then sensory recovery with pain.
		Repeat R. trigeminal rhizotomy.	12.19 52.	Anaesthesia R. face. R. occipital pain persists; pain in ant. half of head and face relieved.

gave partial relief. In a third patient of his ligation of these three vessels along with the external carotid yielded a near-cure; only occasional twinges of pain recurred. A fourth patient had no relief from a high cervical sympathectomy or from subsequent excision of supraorbital and superficial temporal vessels, but division of middle meningeal vessels was then followed by a "cure."

Of the nine cases cited in our Table XXX, whose migraine was treated by occlusion of one or more arteries, we are somewhat surprised to discover on long term follow-up that a useful result has ensued in four. That a simple procedure may yield unexpected success is illustrated by Katherine R. Her attacks of right fronto-temporal pain had led her over 26 years into the offices and hospitals of many fine physicians and surgeons across the country. An artificial menopause, induced when she was 32 years old, yielded no amelioration of pain. A wide variety of medications and local injections had never given her more than a few weeks of relief until Dr. W. J. Mixter divided the right middle meningeal and superficial temporal arteries along with the auriculo-temporal nerve. Presumably the deep artery was important here because the patient referred her pain above the zygoma deeply "almost to the middle of the head," and because a procaine block to the superficial temporal artery and auriculo-temporal nerve did not stop the pain or eliminate deep tenderness. During the six-and-a-half years which have since elapsed the patient has had complete relief.

Division of a single artery along with good medical management has sufficed in two other patients, Edward McF. and Ruth O., but in patient John B. division of the supraorbital, superficial temporal, occipital, middle meningeal and external carotid arteries on the side of the major discomfort did no good. Not until the external carotid was divided on the opposite side did a useful result ensue. This has been maintained for over four years by the additional careful medical management of Dr. John Graham, whereas preoperatively the headaches defied similar conservative therapy. In some of our failures following arterial occlusion we did not pursue the tactic to this logical full extent. In the light of our result with patient John B. we shall probably do this in the future before resorting to trigeminal operations. However, in patient Helen W. division of both external carotid arteries and the middle meningeal on the side of the pain accomplished nothing; hence it seems likely that some patients are going to require division of nerves as well as, or rather than, arteries.

b) By division of vasodilator nerves:—If there is a discharge of impulses in vasodilator nerves during the pain of migraine then their interruption might stop the pain. Because of the concentration of vasodilator fibres to the cerebral hemisphere in the greater superficial petrosal nerve (see

p. 496), Gardner, Stowell and Dutlinger (1947) tried dividing this ne
in patients with migraine. They further emphasized that interruption
afferent pathways for pain in the petrosal nerve may play a supplement
role, and also advocated division of the superficial temporal and mid
meningeal arteries. Although the results they reported in 1947 were
couraging, even more so than in their patients with Horton's type of n
ralgia, Gardner's further follow-up (personal communication, 1951) has
him to retract this suggestion. He finds that less than half of the patie
with migraine obtain enough help from the procedure to justify it. Oli
crona (1947A) from two cases and Falconer (1949) from a "number
cases" were pleased with the results of Gardner's petrosal neurectomy
migraine, but these comments were on the basis of only short follow-u
The lone patient, Helen W., on whom we tried this operation derived
benefit. Rowbotham (1949) also records a failure following this procedu
However, he reports two-year cures in two other patients in whom t
auriculo-temporal nerves were partially excised, and the middle mening
arteries divided in addition to the neurectomy of the greater superfic
petrosal nerve.

2. Division of Afferent Pathways

a) Experimental studies:—Having dealt with the prospects of stoppi
arterial dilation by vascular ligation, or vasodilator neurectomy, we m
now consider how to interrupt the afferent nervous pathways transmitti
pain from arteries, especially from distended arteries. Although vasodi
tion produced by histamine differs from that seen in migraine in at le
eight respects according to Wolff (1948, pp. 289-290), the basic pheno
enon of painful distension of arteries occurs in both. Hence the intraveno
injection of histamine may be used to judge the effectiveness of vario
types of neurectomy in preventing the pain which ordinarily accompani
the distension. Three different groups of workers have studied the effe
on experimentally induced headaches of various types of rhizotomy or sy
pathectomy previously carried out for other reasons.

Complete unilateral trigeminal rhizotomy in a total of 17 subjects r
ported by Pickering and Hess (1933), Northfield (1938) and Wolff (194
p. 192) eliminated headache in the anaesthetic zone in 14. Three still h
some headache referred to the denervated area. From these results o
infers that there is perhaps an 80 per cent chance of relieving by trigemin
rhizotomy headaches secondary to vasodilation which are confined to t
facio-fronto-temporal region. Another patient of Wolff's with hemiana
gesia of face and scalp, caused by disease producing a lesion of the nucle
of the descending trigeminal tract, and of the upper cervical sensory se

ments of the cord, had no pain anywhere in the analgesic area upon injection of histamine. In two patients, one after glossopharyngeal rhizotomy and the other after intracranial division of the VIIth and VIIIth bundle of nerves, histamine headaches were severe and equal on both sides. Pickering and Hess, Northfield, and Wolff all failed to modify histamine headaches in patients who had had first thoracic, or this plus inferior cervical ganglionectomy. Wolff points out, however, that a minor reduction in the afferent input, such as possibly ensues from division of nervus intermedius, glossopharyngeus, or sympathetics, may not be detectable by the patient.

Ray and Wolff (1940) have found that stimulation during operation under local anaesthesia of vertebral and basilar arteries, the proximal portions of their branches, or of dural arteries in the posterior fossa causes pain in the occipital and suboccipital regions. Pain from stimulation of the dura in the lateral wall of the posterior fossa disappeared after section of IXth and Xth cranial nerves in one patient, and the medial dura of this fossa was deprived of pain by posterior rhizotomy of the upper three cervical nerves in another.

If these observations have general validity, individuals with migrainous pain in the posterior part of the head may require extensive denervation for relief.

b) **Clinical experiences:** *i) Sympathetic denervation:* The association of the autonomic nerves with the blood vessels, and of the latter with migraine, have led a number of surgeons to carry out a few sympathectomies. As early as 1923 Jonnesco had reported one good result following resection of the sympathetic chain from the superior cervical down through the first thoracic ganglion. Braeucker (1928) failed to relieve severe attacks in one patient either by division of the internal carotid nerve just above the superior cervical ganglion, or by the addition of anaesthetic block of the inferior cervical ganglion, carried out to exclude impulses via the vertebral artery. Dandy (1931) promised more details if his two early successes with inferior cervical and first thoracic ganglionectomy were followed by others. He never presented the "proof supported by time and additional patients," which in that preliminary note he stated it was incumbent upon him to do. In Craig's similarly treated case (1935), and in Olivecrona's (1947A) two patients with first thoracic ganglionectomy, relief was unattained or poorly sustained. Penfield (1932) recorded three failures in operations which included removal of: 1) superior cervical sympathetic ganglion and carotid plexus; 2) superior cervical sympathetic ganglion, plus plexus and ganglion on vertebral artery, and 3) superior cervical sympathetic ganglion, the upper pole of the stellate ganglion and the plexuses around the carotid and vertebral arteries.

Love and Adson (1936) have had a patient whose migraine recurred six weeks after an operation comprising periarterial stripping of the common carotid, division of the external carotid and removal of the superior cervical ganglion and upper sympathetic trunk on the side of the migraine. They performed bilateral cervicothoracic sympathectomy for some other disorder in five patients who happened incidentally to have migraine. Of these, three were completely and two partially relieved of the migraine for periods unstated. Leriche (1913), Fontaine (1913) and Lenormand (cited by Leriche, 1949, p. 152) have reported favourably on the results of repeated procaine injections in the neighbourhood of the superficial temporal arteries. The relief here may of course have been due to block of the neighbouring auriculo-temporal fibres. Rowbotham (1946) has given us an optimistic account of relief following a bilateral sympathectomy in one case, and a similar procedure on one side in two other patients. He removed the lower half of the superior cervical ganglion, as well as the plexuses on the carotid bifurcation in the neck, and divided the external carotid between ligatures. A fourth patient obtained no relief from an operation which differed only in that the whole superior cervical ganglion was removed. These patients had all been followed less than two years at the time of report. The need for longer follow-up is emphasized by the change in his point of view in 1949, when he stated that the results of sympathectomy have been capricious and therapeutically unsatisfactory. By this time he had carried out a variety of operations in about 100 patients with migraine, and reported on the long-term results in the first 50 consecutive cases. Of these, 17 had had neurectomies in the region of the superior cervical sympathetic ganglion plus either stripping of all three carotid arteries near the bifurcation or division of the external carotid artery. Removal of the stellate ganglion with or without stripping or division of the verebral artery had been done in three more patients.

None of our stellate blocks in three patients with migraine changed the pain; in one the pain actually became much worse. In two of these blocks only procaine was used; the other with alcohol produced a more sustained Horner's sign and anhidrotic hand and face. We were led to think that the pericarotid nerves were implicated in one patient, Katherine F., because traction on either branch of the right common carotid without occlusion started the migrainous pain. However, periarterial stripping of the entire carotid bifurcation, as well as division of the right external carotid along with right upper cervical sympathectomy, gave no relief.

Favourable results in migraine from procedures directed against the periarterial nerves or cervical sympathetic trunk have seemed to us to be too scattered and their rationale too obscure to justify their further use.

ments of the cord, had no pain anywhere in the analgesic area upon injection of histamine. In two patients, one after glossopharyngeal rhizotomy and the other after intracranial division of the VIIth and VIIIth bundle of nerves, histamine headaches were severe and equal on both sides. Pickering and Hess, Northfield, and Wolff all failed to modify histamine headaches in patients who had had first thoracic, or this plus inferior cervical ganglionectomy. Wolff points out, however, that a minor reduction in the afferent input, such as possibly ensues from division of nervus intermedius, glossopharyngeus, or sympathetics, may not be detectable by the patient.

Ray and Wolff (1940) have found that stimulation during operation under local anaesthesia of vertebral and basilar arteries, the proximal portions of their branches, or of dural arteries in the posterior fossa causes pain in the occipital and suboccipital regions. Pain from stimulation of the dura in the lateral wall of the posterior fossa disappeared after section of IXth and Xth cranial nerves in one patient, and the medial dura of this fossa was deprived of pain by posterior rhizotomy of the upper three cervical nerves in another.

If these observations have general validity, individuals with migrainous pain in the posterior part of the head may require extensive denervation for relief.

b) Clinical experiences: *i) Sympathetic denervation:* The association of the autonomic nerves with the blood vessels, and of the latter with migraine, have led a number of surgeons to carry out a few sympathectomies. As early as 1923 Jonnesco had reported one good result following resection of the sympathetic chain from the superior cervical down through the first thoracic ganglion. Braeucker (1928) failed to relieve severe attacks in one patient either by division of the internal carotid nerve just above the superior cervical ganglion, or by the addition of anaesthetic block of the inferior cervical ganglion, carried out to exclude impulses via the vertebral artery. Dandy (1931) promised more details if his two early successes with inferior cervical and first thoracic ganglionectomy were followed by others. He never presented the "proof supported by time and additional patients," which in that preliminary note he stated it was incumbent upon him to do. In Craig's similarly treated case (1935), and in Olivecrona's (1947A) two patients with first thoracic ganglionectomy, relief was unattained or poorly sustained. Penfield (1932) recorded three failures in operations which included removal of: 1) superior cervical sympathetic ganglion and carotid plexus; 2) superior cervical sympathetic ganglion, plus plexus and ganglion on vertebral artery, and 3) superior cervical sympathetic ganglion, the upper pole of the stellate ganglion and the plexuses around the carotid and vertebral arteries

initial good results gave way to a return of less violent attacks, a striking series of long term achievement in this disorder. No statement was made as to the relation of pain to anaesthetic areas in those 10 patients who were not completely relieved.

In two of our patients trigeminal rhizotomy has been carried out after a variety of other operations failed, with a gratifying result in each. In one of these, Margaret J., Dr. Michelsen repeated Penfield's observation that procaine block of the Gasserian ganglion stopped the pain only after anaesthesia extended to the first and second divisions. In the second patient, Helen W., an incomplete trigeminal rhizotomy which spared some *fibres to the upper face, did not relieve the pain. In both a presumably* total trigeminal rhizotomy then stopped the pain. Helen W. is a patient of special interest because of the almost unbelievable amounts of ergotamine tartrate, barbiturates and Demerol which she had been taking. Wolfson and Graham (1949) have already reported her case. She continues free of pain over five years after her rhizotomy. However, in Margaret J. a few cells must have lain behind the plane of division of the rootlets, because the pain recurred 10 years later, at which time some trigeminal sensation was shown to be present. A repetition of the trigeminal rhizotomy in the middle fossa disclosed some intact, probably regenerated fibres, and after division of these the trigeminal zone was again anaesthetic on *that side and the pain in the anterior* half of the head and face was relieved. Some occipital pain on that side persists and may yet require attention, possibly of the type indicated in the next paragraphs.

iii) Bulbar tractotomy: Bulbar trigeminal tractotomy might perhaps be renamed bulbar cephalic tractotomy because it divides pain pathways from all or most of the head (see pp. 464-465). It was first performed for migraine by Rowbotham (1938, case 2). The patient's pain, which was confined to the right forehead, was eliminated (follow-up less than six months). Olivecrona (1947A) has given this operation a thorough trial in typical migraine affecting 15 sides of the head in 13 patients, i.e., two bilateral operations were done. The result was unsatisfactory in only four cases in whom analgesia was not produced in the first divisions of the nerve. This striking correlation of therapeutic failure with technical inadequacy of operation strongly suggests that the afferent impulses active in migraine lie almost exclusively in the descending cephalic (trigeminal) tract.

We think that *bulbar cephalic tractotomy may prove to be the operation of choice in the worst forms of migraine, if necessary with the addition of upper cervical posterior rhizotomy.* It would appear that our technique and perhaps that of Falconer can be counted on to yield permanent analgesia, that keratitis will not develop, and that pain arising from the posterior fossa

ii) Trigeminal denervation: The most logical procedure on the basis of our knowledge of the afferent innervation of the face and the anterior half of the head is to stop trigeminal conduction. By the third decade of this century both Penfield and Harris were doing this. Braeucker (1928) reduced migraine attacks in three patients by alcohol injections into the Gasserian ganglion. In 1932 Penfield reported two carefully studied sufferers in each of whom procaine injection into the Gasserian ganglion, during an attack, stopped the pain at the moment the anaesthesia extended from the lower half of the face to include the forehead. From this he concluded that the fibres of the first division were especially important pathways for the migrainous pain. His subsequent division of the medial part of the trigeminal rootlets gave each patient permanent anaesthesia of the area of the ophthalmic branch of the nerve, with no headaches for three years in one and only mild dull pain in the posterior part of the head and neck in the other.

Rowbotham (1942, 1949) carried out a similar division of medial trigeminal rootlets in 10 patients with six cures, three followed for 10 years and three for six years. One failure was associated with technically inadequate division of ophthalmic fibres. Only a qualified success ensued in two more patients, neither of whom wished to have trigeminal rhizotomy on the other side when pain later developed on that side. A tenth patient remained cured for three years after alcohol injection of the ganglion. Unfortunately the first division trigeminal fibres, which must be divided to relieve migraine, are rarely the easily attacked peripheral branches to the forehead. Of 10 other patients in whom Rowbotham divided supraorbital and supratrochlear vessels and nerves, only one was cured and eight were complete failures.

As usual, one of the largest series is that of Harris (1940B). Having found that alcohol block of peripheral branches would give months of relief to many afflicted with migraine, he attempted to delineate as suitable for ganglionic alcohol injection a particular type of violent migraine which he called "migrainous neuralgia." His criteria for this group tally fairly closely with those of Horton's syndrome (see p. 494), and possibly these results should be reported there under the heading of autonomic facio-cephalalgia. In Harris' cases there were no premonitory symptoms before the attacks and subsequent nausea and vomiting were rare. Duration of attacks was often short—minutes rather than hours; pain was usually in the temple, in or around the eye, upper cheek or nose; the eye frequently lacrimated or became bloodshot; in the detailed case reports nightly attacks were noted in one patient; agony during an attack was often extreme. Of 29 patients treated between 1931 and 1940 by alcoholization of the Gasserian ganglion, there was cure in 19, much improvement in five, and in the remaining five

which left scars on the neck and over the angle of the jaw on one side only. It was relieved by peripheral trigeminal avulsions for two-and-a-half years at first, and on repetition for 12 months. Total left retrogasserian rhizotomy then stopped both the continuous and paroxysmal left-sided pain for the remaining 12 years the patient was followed. Unfortunately the technique for preserving the motor root had not yet been described by Frazier, and the patient had to struggle along with temporary relief from peripheral procedures on the other side. This was not a patient with the usual ophthalmic pain referred to the site of the cutaneous lesion on the forehead. For treatment of the more common purely trigeminal eruption and pain, Harris (1921, 1926) advocated Gasserian alcohol injection; he achieved total anaesthesia and cure of the exhausting pain in "several cases," but did not record more precise data.

Unhappily as more experience has accumulated it has become apparent that procedures directed against the trigeminal roots or descending tract in the medulla have usually been unsuccessful, despite appropriate sensory loss (Frazier and Russell, 1924; Peet, 1929 [two cases]; Sjöqvist, 1948 [two cases]; and Falconer, 1949 [four cases]) In some the paroxysmal pains were relieved but the steady background burning pain continued. In others even the paroxysms were as severe and frequent as ever.

ii) Sympathetic denervation: Disappointments of this type have led to the performance of sympathectomy. Reichert (1936) has reported much relief from removal of inferior cervical, first and second thoracic ganglia. He (1947) also relieved postherpetic pain in the forehead in 10 patients merely by an *incision down to periosteum and extending from the midline* to the outer edge of the eyebrow. Blood vessels as well as nerves were divided with a view to the interruption of sympathetic fibres, but of course somatic afferent fibres were also cut. Hyndman's (1939) original enthusiasm for sympathectomy was based on a good result following Reichert's type of supraorbital incision in one case, and an intracranial cutting of the first and second divisions peripheral to the Gasserian ganglion in the second. Obviously the relief may have been on the basis of dividing trigeminal afferent rather than sympathetic fibres. In a third patient relief was obtained by cutting only sympathetic nerves, but in a further note (1947) he states that none of eight later patients was cured of post-herpetic facial pain by cervicothoracic sympathectomy.

will probably be arrested by dividing the bulbar tract slightly above the obex so as to cut pain fibres travelling via the seventh, ninth and tenth cranial nerves.

E. POST-HERPETIC FACIAL AND CERVICAL PAIN

The pain which may persist, especially in older people, following an attack of herpes zoster is usually a constant burning ache superimposed upon which there may be occasional severe stabs elicited by sensory stimulation. Trigeminal zona is almost as common as that in the thorax and usually involves the ophthalmic division. Happily severe chronic pain after the acute attack is relatively infrequent; Tatlow (1952) encountered only one such problem requiring special treatment in 47 patients followed up after an attack of ophthalmic herpes zoster. Sugar and Bucy (1951) have recently given an excellent review of the subject; in addition to summarizing the literature they report on the results of a questionnaire answered by many American neurosurgeons in 1946.

1. Pathology

An early major contribution was that of Head and Campbell (1900) who, in a classical article, described the posterior root ganglia of the cranial or spinal nerves as the principal sites of damage in herpes zoster. Those patients with continuing pain were consequently treated at first by section of peripheral nerves or posterior roots. In the majority such efforts have failed. The explanation has been given by later studies of Lhermitte and Nicolas (1924) and Wohlwill (1924), which revealed inflammatory changes in the grey matter of anterior and posterior horns of the spinal cord in and near the segment in which the cutaneous eruption appeared. These findings have been amply confirmed (Denny-Brown, Adams and Fitzgerald, 1944) and instances in which the brain was also involved have been described (Lhermitte and Vermès, 1930; Gordon and Tucker, 1945). The number of reported cases subjected to full post-mortem examination of the central nervous system is insufficient to determine the frequency of involvement of pathways for pain central to the primary afferent neurone. In view of the possible irritation of any part of the afferent system from posterior root ganglion to thalamus it is not surprising that denervation at the level of the primary afferent neurone has yielded erratic results.

2. Clinical Experiences

a) Of others:—*i) Trigeminal denervation:* Cushing (1920*B*) was one of the first to present an account of long-term successful treatment of post-herpetic pain in the face. The patient's bilateral pain followed an attack

mesencephalic tractotomy in our Table VIII. Sugar and Bucy's patient was unrelieved by removal of contralateral postcentral cortex for the face, and of the ipsilateral anterior part of the inferior parietal lobule as well. McKenzie's later bilateral frontal lobotomy on this patient gave a useful degree of relief of pain at the price of much loss of initiative. Falconer (1948) secured a similar result from bilateral frontal lobotomy. The pain, referred to the trigeminal third division, had not been relieved 1) by a trigeminal rhizotomy which gave anaesthesia over the second and third division zones; 2) by a trigeminal tractotomy which added analgesia over the rest of the trigeminal zone; or 3) by procaine block of the upper thoracic sympathetic chain. One year after leucotomy the price of continuing relief was an almost total loss of affect. Le Beau's (1950) patient with a good result from a topectomy had only been followed three weeks. Spiegel and Wycis (1953 A and B) report a patient, unrelieved by a previous total retrogasserian rhizotomy, who was maintaining a useful degree of relief one year after their placement of electrolytic lesions in the region of the contralateral dorso-medial nucleus of the thalamus and of the spinothalamic and quintothalamic tracts in the midbrain. In their second patient (1953B) cervical sympathetic block, injection of the sphenopalatine ganglion, trigeminal rhizotomy and postcentral gyrectomy had all failed to give relief. However, four months after they had made their electrolytic lesions the patient was pain-free except for slight dysaesthesia around the eye.

Talairach *et al.* (1949), in a man with post-herpetic facial pain, coagulated in the region of the thalamic nucleus ventralis posteromedialis and centrum medianum of Luys. The early hemihypalgesia regressed rapidly and at two months the pains had recurred in full force. Baudouin and Puech (1949), using a stereotactic apparatus to locate their needle point, have injected procaine into the same region of the thalamus with what they describe as an "excellent and apparently definitive result."

b) **Personal experiences:** The results in our own 11 cases have followed the general trend of more disappointing than successful operations, although we have finally achieved a long-term good result in four patients. We have usually begun with division of appropriate peripheral branches of the trigeminal nerve or the cervical plexus. In one instance, that of Clarence G. (M.G.H. #63458), this alone sufficed to give relief for two-and-a-half years of pain which had been present for three years before operation. In Mary P. (M.G.H. #46494) this also gave good early relief, but since no follow-up was obtainable we have not included her as one of the long-term successes. In patient Irene H. (Case 15, Table XXVI), Mr. J. M. Small's supraorbital neurectomy stopped the unremitting pain in the forehead, which unfortunately recurred *pari passu* with return of sensation

The collected results of American neurosurgeons as tabulated from correspondence with Sugar and Bucy (1951) revealed the following:

	Number of Surgeons Reporting Results (Not number of patients reported)	
	Little or No Relief	*Much Relief or Cure*
Retrogasserian rhizotomy	29	4
Avulsion supraorbital nerve	6	10
Alcohol injection supraorbital nerve	6	3
Trigeminal tractotomy	4	3
Cervical sympathectomy	3	3

When one neurosurgeon reported on several procedures or varying results of one procedure, he was counted in the appropriate additional group.

iii) Flaps of or excision of skin: Total excision of the skin of the painful area has long ago been tried. Sir William Jenner's patient (cited by Harris, 1926, p. 287) obtained no relief from his intolerable agony following this operation and later shot himself. Browder has treated post-herpetic pain in the forehead by incising down to the bone on all sides of the involved area except at the midline. Dr. Robert Watson (cited by Sugar and Bucy) has carried out a similar operation, reflecting a flap of scalp with the skin over the zygoma as the hinge, and removing the muscles, vessels and nerves between galea and periosteum. De Vet (1952) has independently thought of turning back a flap of that part of the skin affected by the herpetic eruption. He removes the subcutaneous fat and even undercuts the skin of the eyelids if pain is referred there. Of his eight patients with ophthalmic pain, seven have been given complete relief, after one operation in four instances, and after a second operation in three. Follow-ups in this happy group run from six months to five years. The eighth patient's pain was referred to the eyeball and inside the orbit; division of the greater superficial petrosal nerve gave only partial relief. De Vet has now taken the logical step of studying histologically the abnormal skin in these patients, searching for irritative lesions of the peripheral nerve fibres and their endings. Talairach *et al.* (1949) mention that a skin graft over the zone of greatest post-herpetic pain around the eye of their patient failed to give relief because non-grafted areas on the nose, cheek and eyelid then became painful. Had they followed up this tactic as thoroughly as de Vet has done an intracranial operation might have been unnecessary.

iv) Operations on the brain: The presence of central lesions in the disorder and the large number of patients unrelieved by peripheral procedures have led to trial of operations on the brain. We have summarized the dubious results of Vincent's pontine tractotomies on p. 229, and of

it clear that there must be a central lesion which includes pain pathways. That thalamic lesions can give rise to such pain has been accepted and repeatedly confirmed since the classical account of Déjerine and Roussy (1906). In this article they cite seven other authors who had previously described pain as a feature of thalamic lesions. Such pains show many or all of the following features: 1) spontaneous, constant character which may have an aching, boring, gnawing, burning, icy, crushing or ineffably unpleasant quality; 2) superimposed there may be spontaneous paroxysms or these may be evoked by external stimuli; 3) threshold for appreciation of pin as painful may be elevated; 4) the reference of pain is then usually over a wide area which may or may not include the spot stimulated; 5) touch, heat, cold and pinprick may all evoke the same diffuse, peculiarly disagreeable sensation more unpleasant than pain evoked from the normal side; 6) there is often an abnormally long period between the onset of effective stimulus and the sensation which may then 7) long outlast the stimulus.

It has become apparent that pain which has many or all of these features can be produced not only by thalamic lesions, but also by appropriately placed injury in the cord, bulb, pons, midbrain, or cerebral hemisphere. Thus such pains over limb and torso on one side occurred in Kendall's case 1 (1939), associated with a lesion of the lower cervical spinal cord. Pains in the neck and occiput in the patient of Foix *et al.* (1922) were probably due to a syringomyelic lesion, which at autopsy extended from the lower cervical to the T6 segments; intense pains in both legs in Spiller's (1923) case of syringomyelia could not be accounted for by irritation of posterior roots. Davison and Schick (1935) in a comprehensive review of the subject cite five other authors and add four cases of their own in which lesions of the spinal cord produced "central pain."

We have already commented at length on the similar pains which may appear after thrombosis of arteries supplying the area adjoining the lateral fossa of the bulb (p. 452). A particularly well studied case is that of Foix *et al.* (1922). The patient had continuous burning pain in both sides of the face, worse on the right. Paroxysms of more severe pain supervened whenever a current of air or some cold water touched the face. There was no objective sensory loss. At post-mortem two small cavities occupied nearly symmetrical areas within the nuclei of the descending trigeminal tract in the medulla The much larger one on the right side corresponded to the side of the worse pain. The pain and paraesthesias produced by such lesions not only present a therapeutic problem for the neurosurgeon, but give him real concern lest his surgical lesion in such regions create additional similar symptoms. Much to our discomfort we have witnessed

in three months. Our bulbar tractotomy yielded analgesia and complete relief of pain; the sensory loss persisted almost unchanged 33 months postoperatively, only to fade in the course of the next five years from the second and third divisions with return of pain. It has been relieved again by Professor Brodie Hughes' successful injection of the ganglion with alcohol. The result in Irene H. suggests that, if relief lasting for months is obtained from peripheral neurectomy, section of root or tract is likely to give more permanent good results. A third patient, Alice B. (M.G.H. #353648), has been relieved of pain for nine years since a C2, 3, 4 posterior rhizotomy. A useful result was finally achieved in a fourth patient, Joseph T. (Case 37, Table XIII) by bilateral orbital corticectomy in two stages after technically complete trigeminal and sympathetic operations had failed.

Our fruitless operations: Four patients had relief for not more than two to three weeks from supraorbital, sometimes associated with supratrochlear, neurectomy. Three of these had subsequently a trigeminal rhizotomy which, despite the total facial anaesthesia on that side, was equally valueless. Two patients had no relief from cervical plexotomies; in one of these a posterior rhizotomy (C2-C5) also failed. A similar operation in the second patient was followed by death on the eighth postoperative day. Another patient did not die for a month after C2, 3, 4 posterior rhizotomy, but his condition was too poor for us to judge the degree of relief postoperatively.

Procedures on the sympathetic system were a total loss; in one patient a stellate block which produced a Horner's sign gave no relief; in another patient such a block with relief of pain was followed by ganglionectomy with no relief. Cervical sympathectomy in another patient also accomplished nothing. Another patient was a real disappointment because even her fourth operation, a bilateral frontal leucotomy, failed to give useful relief of pain even though it produced mental deterioration (Elizabeth M., M.G.H. #257996).

We conclude that procedures directed at the primary afferent neurone and/or elevation of skin flaps should be tried in this disorder before one resorts to operation on the midbrain, thalamus or frontal lobes. Retrogasserian rhizotomy, however, should only be carried out if previous neurectomies have been followed by a promising period of relief.

F. "CENTRAL PAIN"

I. Pathology and Clinical Features

We have already initiated a discussion of this field in our comments on post-herpetic pain in the preceding section. We now have to consider patients in whom the syndrome surrounding the onset of complaints makes

Doctors Horrax and Poppen excised the abnormal tissue lining a large porencephalic cyst.

2. Treatment at the Primary Afferent Neurone, Spinal Cord, or Postcentral Cerebral Cortex

Acting on the assumption that the usual idiopathic trigeminal neuralgia was due to a tiny thalamic lesion, the pain from which was relieved by rhizotomy, Frazier, Lewy and Rowe (1937) tried to stop typical thalamic pain by denervations caudal thereto. Their patient's cerebral vascular lesion provoked intense constant pains plus superimposed paroxysms throughout the left side from head to foot, accompanied by severe hypalgesia and hypaesthesia. An alcohol injection into the left Gasserian ganglion relieved all of the trigeminal pain and paraesthesias. Right anterolateral cordotomy at C5, plus crushing of the left posterior roots of C2 and C3, freed the woman of the rest of her pain and dysaesthesia in the left limbs and torso, although a preliminary spinal anaesthesia had made it worse. Eight months later pinprick felt somewhat sharp at the left ankle, and the pain had started to recur in the left limbs and just in front of the left ear. Repetition of the Gasserian alcohol injection stopped the latter pain. A cordotomy on the *left* side at C5 stopped most of the remaining ipsilateral left-sided pain and yielded analgesia of the entire right side from the shoulder down as well. Deep pinprick was still painful at the left heel and the persisting subjective complaint of pain was mostly referred to this spot. The relief continued till death two months later. Turnbull (1939) rang up another success by a left anterolateral cordotomy at C3 which also produced analgesia on the opposite side from the shoulder down. Pain in this patient had been confined to the forearm and hand and was probably on the basis of a syphilitic endarteritis of a thalamogeniculate branch of the left posterior cerebral artery. It had not been relieved by intensive antiluetic therapy or by a previous procaine block of the sympathetic nerves to the right upper limb, but both steady and paroxysmal components of the pain remained absent at follow-up one year after cordotomy.

Unfortunately the above represent isolated successes. The usual course of events following such therapy is typified by our patient Marion H. (M.G.H. #519080). Her constant crushing pain in the right lower face with added bouts of right fronto-temporal pain followed thrombosis of an artery to the right lateral portion of the medulla. The following procedures gave no significant relief: 1) alcohol injection of right trigeminal third division which produced hypaesthesia and hypalgesia over this area; 2) alcohol injection of right Gasserian ganglion which produced total trigeminal sensory loss; 3) right thoracic sympathetic alcohol injection which

several complications of this sort following bulbar trigeminal tractotomy and upper cervical anterolateral cordotomy (see pp. 255, 453).

Pontine lesions causing pain have been reported by von Economo (1911), Weisenburg and Stack (1923, two cases), Mills (1923) and Kendall (1939, two cases of pontobulbar glioma). The first author's case was noteworthy *in the presence of complete analgesia and thermanaesthesia in the* right limbs and torso, which were nevertheless accompanied by such severe pains that those in the right chest interfered with breathing, those in the right abdomen simulated colic, and morphine was required to permit sleep. At postmortem a tuberculoma was confined to the left pons. We note in our discussion of mesencephalic tractotomy the painful paraesthesias often provoked by this operation, but we have not seen a report of such symptoms associated with nonsurgical lesions in the mesencephalon.

Foerster (p. 120-121, 1927A), in what appears to be a somewhat fanciful flight, has used patients with central pain as a basis for hypothecating the existence of a central corticofugal pathway inhibiting pain impulses. He explained certain hyperpathias on the basis of destruction of such pathway in the posterolateral column of the spinal cord in one instance, and in the medial lemniscus in another patient who had a pontine tuberculoma. In patients with disorders in cord or brain stem in whom severe hypalgesia is combined with hyperpathia and spontaneous pains he has another explanation. He presumes that a pain pathway consisting of short chains of neurones harbours a lesion capable both of interfering with the normally ascending impulses of pain and of provoking *de novo* such impulses in the links of the chain at the rostral end of the lesion This seems more plausible, and at least has the merit of invoking no hitherto undescribed pathways.

Cerebral pain producing ischaemic lesions, which spared the thalamus, have been found by Davison and Schick (1935) in two postmortem examinations. These were situated at the level of the cortex and subcortical white matter in the parietal lobe and insula. A thalamic lesion was strongly suggested by the clinical picture in their case 10; the picture of central pain was less pronounced in their case 11. They include several earlier reports of cerebral tumours causing such manifestations and Horrax (1946) has added another such case. We have already cited Michelsen's (1943) paper describing from M.G.H. records four patients with neoplasm and one with trauma of the cerebrum who had central pain. Particular emphasis may be placed on the cerebral cases because the neurosurgeon must be certain that the "thalamic pain" is not due to a remediable lesion here before he attempts to treat the pain alone. Kozol's patient (1938) with a full-blown "thalamic syndrome" had relief, not only of her terrible pains, but also of her convulsions during the two year period of follow-up after

2 and 5, nucleus ventralis postero-medialis plus centrum medianum; cases 3 and 4, ventral portion of dorso-medial nucleus plus centrum medianum. The results: case 6, pain free till death from bronchopneumonia at four months; case 2, moderate recurrence of pain two-and-a-half months postoperatively, but not much further worsening in the next eight months; case 5, disappearance of pain but death four days postoperatively; case 3, still free of pain several months after operation; case 4, no pain but some paraesthesias five months later. With this initial encouragement these other enterprising pioneers may well work out a useful procedure.

A single patient with thalamic pain in whom cocaine was injected into the nucleus ventralis posterior by Baudouin and Puech (1949) obtained only temporary relief, even though a crossed hemianaesthesia was produced.

The treatment of "central pain" is still in an evolutionary stage; no clearcut recommendations are feasible from the evidence at present.

G. PAINFUL CONVULSIVE TIC

Cushing (*1920B*) described two patients of his own and mentioned two others he had seen in whom motor spasms of facial muscles were accompanied by severe paroxysms of pain. He distinguished these from others whose facial contortions were merely secondary to the pain of typical trigeminal neuralgia. Neither of his own patients nor one of the two others he had seen was relieved by a removal of the Gasserian ganglion. One of his patients then secured incomplete relief for six months from a spino-facial anastomosis, but the fourth case was permanently cured of pain by such an operation. Harris (1926, p. 325) describes a patient with this disorder who was relieved of both pain and muscle spasm by a Gasserian alcohol injection. Although he presents no evidence that his curative injection affected the seventh nerve, he classifies the disorder with geniculate neuralgias, apparently because pain was provoked by placement of a finger in the ear, but not by handling the face. Harris has had another patient whose clonic facial spasms had been present for 30 years, whereas paroxysms of severe facial pain on that side had been present for only five years. Alcohol injection of the trigeminal nerve stopped the pain, but the motor spasms continued until arrested by alcohol block of the facial nerve at the stylomastoid foramen. Glaser (1940) also had a patient in this general category, whose facial pain was, however, continuous, although much worse during the spasmodic contractions of his face Non-surgical treatment sufficed to give him a useful modicum of relief.

From the brief descriptions of these patients, it is apparent that interruption of the fifth or seventh cranial nerves is at times effective in stopping both pain and clonic spasm, but that one may have to deal with both nerves in order to stop both symptoms in some cases.

yielded a hot dry right upper limb and face; 4) right total trigeminal rhizotomy. Our patient Helen C. (M.G.H. #632940) had a typical thalamic syndrome. Her cordotomy at the second cervical segment, which gave an unusually high cutaneous level of analgesia (to the C3-4 junction at the clavicle two months postoperatively), did not stop the pain anywhere in the limbs or torso, and the relief from subsequent postcentral gyrectomy was satisfactory for only a few months. The relatively poor results achieved in this disorder by others who have removed the postcentral cerebral cortex are described in Chapter X, p. 338.

3. Treatment at the Mesencephalon, Thalamus or Frontal Lobes

Reports of a few operations on the frontal lobes for pain of this type have appeared. Scarff (1950) did one of his unilateral prefrontal lobotomies in the dominant left hemisphere of a patient with left-sided, post-apoplectic thalamic pain. The result was "good" at four months, i.e., the patient no longer volunteered a complaint of pain and required no narcotics. Our single experience with Scarff's operation in a very similar case has been reported on p. 323. Pauline C., who had a rheumatic heart, developed a left hemiparesis from an embolic infarction. Her severe burning pain in the paralyzed left arm was relieved until she died four years later from another embolus In addition, her previous tension and uncooperative behaviour were greatly improved.

Le Beau (1950) gives an account of the very early results in three patients with the thalamic syndrome and in one with postencephalitic pain following his 10-12 gram removals of frontal cortex on each side. One died and a good result was achieved at two months in only one of the three others.

The first workers in the field of electrocoagulation deep in the brain, Spiegel and Wycis, *have used their method in two patients* with central pain (1953A). In the hope of relief from left facial pain, their case 4 had already undergone left total retrogasserian rhizotomy, right postcentral corticectomy (face area) and left prefrontal lobotomy. The placement of bilateral mesencephalic lesions at the level of the superior colliculus was followed by freedom from pain for four-and-a-half months, then recurrence at the original severity. Their case 5 had left facial pain from a pontine vascular lesion. Block of the left stellate ganglion and a right prefrontal lobotomy gave no relief. Nine months after electrolytic lesions had been placed at the most rostral part of the midbrain in the region of the spinothalamic and quintothalamic tracts he was still free of pain.

Electrocoagulation in the thalamus has been used in the treatment of this disorder in five cases by Hécaen *et al.* (1949). The surgical lesions were thought to lie as follows. case 6, centrum medianum of Luys; cases

2. Differential Diagnosis

There are a few additional disorders causing cephalic pain which should be recognized so that proper treatment can be undertaken. *Arteritis* involving temporal or other vessels of the scalp may be associated with similar lesions of intracranial vessels. Tenderness of the scalp especially over the course of superficial arteries, palpable thickening around these vessels, decreased pulsations in some of them, and reference of the pain superficially to the scalp itself are cues to this diagnosis. The highly successful treatment consists of resection of small portions of the affected arteries. In the three of our patients in whom the pathologist confirmed the diagnosis after this manoeuvre, almost complete relief of the pain has been maintained for the four to eight years of subsequent follow-up. In Costen's "*temporomandibular neuralgia*" (1934, 1936) headache is the commonest symptom; reference is to vertex, occipital, periauricular or supraorbital areas. Burning in the throat, tongue and side of the nose are also common. Saliva may be diminished or excessive in amount. The lesion is said to consist of a medial movement of the mandibular condyle, causing pressure against auriculotemporal and chorda tympani nerves. Reposition of the jaws by dental prostheses is said to give relief.

3. Operations on Peripheral Pathways

Neurosurgeons have been attracted to the task of giving relief to patients with the cryptogenic pains of atypical facial neuralgia on the plausible assumption that, even if the cause is not known, it ought to be feasible to divide the appropriate pain pathways. If the attack is to be on peripheral nerves, Figure 121 indicates the complexity of the choice. The basic fact which emerges from this century old illustration is that nearly all of the lower cranial nerves communicate at some point with each other, and have an abundant assortment of connections with the cervical and sympathetic nerves as well. Goodness knows what random pathways may be taken by pain fibres wandering through this almost limitless plexiform maze. At one time or another various workers have fixed their attention on some small segment of this network and attributed vast importance thereto.

a) Sphenopalatine ganglion:—This structure held such a fascination for Sluder that about two-score of his publications deal exclusively with or hover around the "syndrome of the sphenopalatine (Meckel's, nasal) ganglion." He says (1927, p. 93) that the typical patient has had coryza, "sometimes astonishingly slight and often forgotten." "A short time later, pain began at the root of the nose, in and about the eye, the upper jaw

H. ATYPICAL FACIAL NEURALGIA

Doctor Francis Grant was recently asked at a Symposium of the American College of Surgeons how to treat atypical facial neuralgia. He replied, "I don't know. I usually send these patients to see someone else as soon as I can." We share his perplexity and the following paragraphs will serve chiefly to emphasize our ignorance in this field.

1. Clinical Features

After one has separated out all of the various syndromes and causes of pain about the face and head described in the foregoing sections, one is left with a group of patients in whom both cause and treatment of the faciocephalic pain are obscure. In this unsatisfactory category the pains or the people who are afflicted with them tend to show these characteristics:

1) No limitation to the area supplied by a single nerve, but spread to the zones of several sensory cranial or cervical and cranial nerves.

2) No limitation to one side of the face or head, but often simultaneous bilateral reference.

3) *Constant* rather than paroxysmal nature of attacks, lasting without surcease for days or months rather than for seconds or minutes; severe exacerbations may be superimposed.

4) External stimuli, movements or other activity of the patient do not precipitate attacks or worsen pain already present.

5) Reference to deep rather than superficial tissues with tendency for the patient's descriptive terms to suggest painful pressure, e.g., "gripping," 'drawing," "pulling," "boring," "bursting."

6) Tendency for drug addiction to develop whereas in those with typical neuralgias this does not occur because even narcotics usually give the latter such inadequate relief.

7) Generalized neurotic or neuropathic personality often present.

8) Many authors include in this group patients with symptoms of autonomic effector activity typical of, or reminiscent of, autonomic faciocephalalgia (Horton's syndrome). We think these deserve separate consideration, although intermediate forms occur.

No one of these foregoing criteria is essential to the diagnosis. Moreover, the pain arising from deep-seated infections or from tumours of face, head or cranial cavity may show similar characteristics, so that thorough studies are required to eliminate such diagnoses as well as others previously mentioned in this chapter.

itching in the hard palate, shoulders and upper extremity, and pain in the hard palate or nasal fossas. He also makes the statement that cases of stiff and sore neck are primarily cases of "neuralgia of the nasal ganglion"! This ill-defined syndrome in which appears no mention of type, duration or incitants of pain he has also called "lower half-headache." He rests his nebulous case for implicating the sphenopalatine ganglion on the allegation that all such pains stop when cocaine or a caustic such as silver nitrate is applied to the nasal mucosa in the region of the sphenopalatine foramen near the ganglion.

Other authors in equally uncritical accounts describe the same syndrome complete to the zone of tenderness 3-5 cm. behind the mastoid process, and the same successful treatment (Gaudet, 1924). Sluder was able to secure equally felicitous results by this treatment of his favourite bit of nasal mucosa in a whole host of symptoms of other disorders, ranging from the photophobia of glaucoma to the dyspnoea of asthma. He presents no evidence that any of his methods actually stops nervous conduction in the sphenopalatine ganglion. (When numbness in the face is produced this is probably due to interruption of the maxillary division of the trigeminal nerve.)

Critical evidence refuting the concept of frequent conduction of pain via this ganglion in this disorder has been presented. In a patient in whom Sluder had made the diagnosis of neuralgia of the ganglion, Cushing's total extirpation of that structure had no effect on the pain (1920*B*, p. 162). Frazier and Russell (1924), Braeucker (1928) and Fay (1932) each had a similar disappointing experience from such an operation. Cushing drew attention to the fact that in the 19th century removal of Meckel's ganglion in the treatment of various facial neuralgias had a period of popularity and was soon abandoned (Fowler, 1886). Perhaps the ease of cocainizing the nasal mucosa and the lack of simple effective treatment of atypical facial neuralgia are the principal reasons for the persistence of this almost uniformly futile tactic.

b) Vidian nerve:—Another structure singled out for attention in atypical facial neuralgia has been the Vidian nerve. This is formed by the juncture of the great superficial and great deep petrosal nerves at the foramen lacerum near the posteromedial corner of the middle cranial fossa, leaves the skull via its own separate canal near the inferolateral bony wall of the sphenoid sinus and runs into the sphenopalatine ganglion. Sluder considered this nerve as a possible seat of neuralgia and made this diagnosis in several patients (1927, p. 329-330). In 1915 he stated that his electrical stimuli to the Vidian nerve in the sphenopalatine fossa evoked "pain in ear, mastoid, occiput, neck, shoulder blade, shoulder, arm, forearm and hand." At that time he used the term Vidian neuralgia to describe

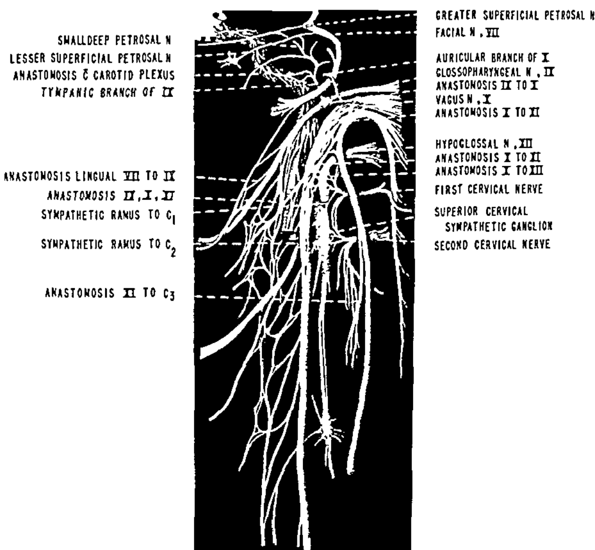


Fig. 121. Connections between nerves—lower cranial and upper cervical.

Only a few of the rich supply of anastomoses are labelled in this figure. Many of the others can be seen on careful inspection of the drawing

From L Hirschfeld. *Traité et Iconographie du Système Nerveux et des Organes des Sens de l'Homme*, 2nd ed, 1866 Courtesy, Masson et Cie., Paris.

and teeth, sometimes also the lower jaw and teeth, and extended backward to the temple and about the zygoma to the ear, causing earache; emphasized at the mastoid, but always *severest at a point 5 cm. back of that* (which is almost always quite sensitive to pressure); thence reaching backward by way of the occiput and neck, it may extend to the shoulder blade and shoulder (less often to the axilla and breast), and in severe attacks to the arm, forearm, hand, and even the finger tips."* As less frequent features of this clinical picture he describes a "stiff aching throat,"

*Sluder, G.: *Nasal Neurology, Headaches and Eye Disorders* St. Louis, Mosby, 1927, p 93.

itching in the hard palate, shoulders and upper extremity, and pain in the hard palate or nasal fossas. He also makes the statement that cases of stiff and sore neck are primarily cases of "neuralgia of the nasal ganglion"! This ill-defined syndrome in which appears no mention of type, duration or incitants of pain he has also called "lower half-headache." He rests his nebulous case for implicating the sphenopalatine ganglion on the allegation that all such pains stop when cocaine or a caustic such as silver nitrate is applied to the nasal mucosa in the region of the sphenopalatine foramen near the ganglion.

Other authors in equally uncritical accounts describe the same syndrome complete to the zone of tenderness 3-5 cm. behind the mastoid process, and the same successful treatment (Gaudet, 1924). Sluder was able to secure equally felicitous results by this treatment of his favourite bit of nasal mucosa in a whole host of symptoms of other disorders, ranging from the photophobia of glaucoma to the dyspnoea of asthma. He presents no evidence that any of his methods actually stops nervous conduction in the sphenopalatine ganglion. (When numbness in the face is produced this is probably due to interruption of the maxillary division of the trigeminal nerve.)

Critical evidence refuting the concept of frequent conduction of pain via this ganglion in this disorder has been presented. In a patient in whom Sluder had made the diagnosis of neuralgia of the ganglion, Cushing's total extirpation of that structure had no effect on the pain (1920*B*, p. 162). Frazier and Russell (1924), Braeucker (1928) and Fay (1932) each had a similar disappointing experience from such an operation. Cushing drew attention to the fact that in the 19th century removal of Meckel's ganglion in the treatment of various facial neuralgias had a period of popularity and was soon abandoned (Fowler, 1886). Perhaps the ease of cocainizing the nasal mucosa and the lack of simple effective treatment of atypical facial neuralgia are the principal reasons for the persistence of this almost uniformly futile tactic.

b) **Vidian nerve:**—Another structure singled out for attention in atypical facial neuralgia has been the Vidian nerve. This is formed by the juncture of the great superficial and great deep petrosal nerves at the foramen lacerum near the posteromedial corner of the middle cranial fossa, leaves the skull via its own separate canal near the inferolateral bony wall of the sphenoid sinus and runs into the sphenopalatine ganglion. Sluder considered this nerve as a possible seat of neuralgia and made this diagnosis in several patients (1927, p. 329-330). In 1915 he stated that his electrical stimuli to the Vidian nerve in the sphenopalatine fossa evoked "pain in ear, mastoid, occiput, neck, shoulder blade, shoulder, arm, forearm and hand." At that time he used the term Vidian neuralgia to describe

pain of such distribution. Vail (1935) has contended that the syndrome of Meckel's ganglion described by Sluder is always a Vidian neuralgia. He points out that the long canal of this nerve may stand out as a ridge between the medial and lateral pterygoid recesses of the sphenoid sinus, that the bone over the canal may even be absent. He has had one patient in whom he saw by nasopharyngoscope during each recurrence of pain an inflammation in the sphenoid sinus. He was also able to induce an attack of pain by injection of 40 per cent iodized oil into the sphenoid sinus. The arguments he adduces through four publications appear to rest largely on his experiences with this one patient (1929, 1932, 1933 and 1935). While the work of Sluder and Vail demonstrates that inflammation of nasal cavities or accessory nasal sinuses may on occasion produce pain of the type in question, such a lesion is rarely present during these attacks.

c) **Arteries and sympathetic nerves:**—Fay (1932) has concentrated his attention on the blood vessels in his efforts to understand the atypical neuralgias. He states that pressure on the common carotid arteries just below the bifurcation causes a severe pain on the side of the neuralgia "in almost every case where patients have complained of chronic, dull, aching pain referred to the eye, deep in the malar region and traced back to the ear, behind the ear, or down the neck." This painful response which he has called "carotidynia" has not been widely confirmed. Upon stimulation under local anaesthesia of exposed external and internal carotid arteries and their branches, he has often elicited pain which is usually referred to the area supplied by the arterial branch in question. He has concluded that pain impulses arising in the carotid vascular tree must enter the central nervous system by one or more of three routes: "1) the vagus, 2) the sympathetic chain, or 3) the carotid sheath to the base of the neck, and thence into the cervical-thoracic posterior roots." In support of his contention that the pain impulses enter the cord at the cervico-thoracic junction, he has carried out high spinal anaesthesia and states that when the level of sensory loss reaches T1 the malar pain and "carotidynia" of atypical facial neuralgia disappear. In a series of 19 patients he carried out a variety of operations, dividing lower cranial nerves, cervical plexus or roots, sympathetic chain, or denuding common carotid artery and its branches. No two patients had the same series of operations. Although seven of the 19 patients were said to be greatly improved or completely relieved, the duration of follow-up is not stated. The variation in the procedures performed suggests that the surgeon was convinced of the efficacy of no one of them. We are inclined to explain Fay's success on the basis of a gradual reduction by the series of procedures in the number of available pathways for pain to reach the brain. The last operation alone might not necessarily

have been any more effective than the first. He mentions still another case of "extreme atypical neuralgia" in which he divided "the anterolateral columns of the cord at the Vth cervical segment with complete relief of pain referred to the face, jaw and malar region." He presumed that this interrupted secondary fibres related to sympathetic afferents from the head entering the cord in lower cervical or upper thoracic segments.

Schmidt and Szujewski (1948) confirmed Fay's finding of "carotidynia." They noted in four patients that "careful stimulation of the carotid sinus on the affected side usually produced an attack of pain similar to that which the patient had." These patients were all treated by operative denudation of the carotid vessels in the neck, but the follow-up in all was unfortunately too brief to give significance to the described relief.

The efforts of others to implicate the sympathetic nerves in atypical facial neuralgia have also at times seemed to bear fruit. Braeucker (1928, pp. 167-171) had a patient whose pain persisted following removal on the left of both Gasserian and sphenopalatine ganglions. All of the pain in the left face, head, neck, shoulder and upper limb stopped following divisions on the left of the rami communicantes C1-C4 along with branches from the superior cervical sympathetic ganglion and hypoglossal nerve to the external carotid artery.

Foerster, Altenburger and Kroll (1929) had a similar result in a patient whose constant pain in the upper jaw was not relieved by resection of that part of the Gasserian ganglion related to the second trigeminal division. This operation gave the desired cutaneous anaesthesia, but pressure against the upper jaw and a deep needle prick were still painful. Excision of most of the cervical sympathetic trunk from the superior ganglion on down plus removal of the plexus over the carotid bifurcation gave much relief. During the operation stimulation of either the external carotid plexus or sympathetic trunk reproduced the patient's pain. Dull pain still persisted on deep pressure or needle prick against the upper jaw. This and a remnant of spontaneous pain disappeared following an alcohol injection into the sphenopalatine ganglion, entrance into which was signalized by a profuse flow of tears from the ipsilateral eye. Incidentally we are aware of no other patient in whom pain conduction via sphenopalatine ganglion as separate from the maxillary nerve has been thus demonstrated. Duration of follow-up is not given in either of these two patients.

Frazier's (1928B) thorough trial of sympathectomy in patients with atypical facial neuralgia yielded disappointing results. He removed the superior cervical sympathetic ganglion and the plexus on the common carotid artery in 13 patients. Relief lasted for nine months in one, and was present early after operation in another patient who could not be traced; the rest were failures. Reasoning that the pain might follow other branches to a

lower level of the sympathetic, Frazier asked one of us, while visiting his clinic, to block the stellate ganglion. Infiltration of this structure was accomplished without benefit. We have, however, had a single unequivocal good result following cervico-thoracic sympathetic ganglionectomy in atypical facial neuralgia. The success of the procedure must be credited to Dr. James Campbell, who first performed the operation on the left side and then referred the patient to us when the pain recurred on the right. As she serves to point out that sympathectomy cannot be dismissed altogether in treating these difficult cases and that diagnostic procaine block should be tried routinely, her history is abstracted below:

Mrs. Edith D., 41, (M.G.H. #155885) had had a total sensory root avulsion of the right trigeminal nerve in 1944 by Dr. W. J. Mixter. Her pain, although coming in attacks limited to the trigeminal area, was not exactly typical of tic douloureux and there was no trigger area. With a history of multiple operations, nervousness, and fatigue she had been regarded as a psychoneurotic suspect by her physician, Dr. Reed Harwood. Unfortunately trigeminal alcohol blocks had not given clear-cut anaesthesia. This was produced by the rhizotomy and her paroxysmal tic was relieved. She reentered a year later complaining of a steady dull pain in the lower right side of her face and a "roaring" in her head. After a normal arteriogram the R. common carotid artery was ligated and the periarterial plexus of nerves at the carotid bifurcation stripped. Neither this procedure nor a subsequent ligation of the external and internal branches of the artery produced any change in her symptoms, although it was observed that traction on the artery reproduced her pain.

In 1947 she entered the Peter Bent Brigham hospital complaining of a continuous aching pain in the L. (opposite) side of her face which was severe, and also a milder steady neuralgia on the side of Dr. Mixter's operation. After numerous procaine blocks of the stellate ganglion on either the R. or L. side had invariably relieved the neuralgia over the period of sympathetic paralysis, Dr. Campbell removed the stellate and second thoracic ganglia on the left side. The neuralgia on this side was then relieved completely, but on the original R. side it continued to increase to a degree that required 0.5 gram of Pantopon each 24 hours for relief. Although we were most reluctant to believe that the deep aching pain in orbit and cheek would respond to sympathectomy, the patient stated that it disappeared synchronously with the development of R. stellate block with procaine. With this encouragement, the first and second thoracic ganglia were removed on this side on 3/12/49. After operation Dr. Harwood reported that it took several weeks to break her addiction to narcotics. Nevertheless she stated that she was entirely free of pain and able to do all her own housework within six weeks and so remained at her last visit three years after the first and 18 months after the second sympathectomy.

A moderately encouraging result was also attained in patient *Melissa B.* (M.G.H. #333021), aged 46 years in 1949. Thirteen years previously a severe febrile illness lasting six weeks was followed by a torticollis in which the head was turned to the right. In the left side of the neck there was pain which later involved the left face and head, and lasted hours to days at a time, continuing despite disappearance of the torticollis. In addition there were attacks of left hemicranial migraine unrelieved by ergotamine tartrate s.c. or orally. All of the pain, including the attacks of migraine, had stopped for two years following anterior scalenotomy and resection of a left cervical rib in March 1942, but then recurrence gradually took place. Procaine block of the left C2, 3, 4 nerves gave "about 60 per cent relief," but the patient objected to the numb feeling. Perivascular procaine block at the carotid bifurcation and procaine into the scar of scalenotomy gave about the same degree of temporary relief, but saline infiltration was much less effective. Compression of the common carotid artery also stopped most of the faciocephalic pain. She was addicted to Demerol and Methadon.

In December, 1949, the cervical sympathetic trunk was exposed. Stimulation just above the middle cervical ganglion produced a severe burst of her previous type of pain in the left jaw, face, side of the head and ear. Following division of the trunk just above the middle cervical ganglion, stimulation of the rostral end of the trunk caused the same response whereas stimulus to the caudal end caused only pain in the left axilla. No other procedure was carried out. After two more days, continuance of the pain virtually stopped and, to our surprise, has remained much reduced in the ensuing 18 months. Occasional similar right-sided pain and attacks of migraine incapacitating her for two days per month have continued.

d) **Other peripheral operations:**—From the vast material of Frazier's clinic at the University of Pennsylvania, Glaser (1928) presents a discouraging total picture of atypical neuralgia. Of 143 cases in this category which he subjected to critical analysis not a single one was relieved by any therapeutic measures tried. These included:

Injection of alcohol in branches of the trigeminal nerve	64
Cocainization and injection of the sphenopalatine ganglion	50
Extraction of teeth	48
Operations on sinuses	48
Supraorbital and infraorbital nerve avulsions	24
Nasal operations	15
Cervical sympathectomy	12
Stripping of the periarterial (carotid) plexus	10
Subtotal section of sensory root of trigeminal nerve	11
Mastoid operations	5
Pelvic operations	5

Seven of these patients had what Glaser called sympathetic phenomena which included lacrimation in 33, orbital oedema in 25, anisocoria in 13,

corneal (sic) injection in 11 (probably conjunctival rather than corneal), nasal discharge in 11, facial flushing in 18, nausea and vomiting in 24. Some, perhaps many, of these patients, e.g., case 9, (p. 551), clearly fall into the category to which Horton has drawn attention and which we have described separately. In others, however, e.g., case 7 (p. 549) the pain was constant and accompanied by exacerbations associated with flushing and oedema of the face; and 67 of the 143 had no such manifestations at all.

Härtel (1935) also mentions failure to relieve the pain of atypical neuralgia in every one of 13 cases in whom he carried out a Gasserian injection with alcohol.

Wolff (1948, p. 416 et seq.) has classified the entire group of patients with atypical facial neuralgia in his "painful vascular syndrome of the face and head." He has shown that the attacks of pain are relieved by intravenous injections of ergotamine tartrate in many of those patients who also have signs of autonomic effector activity. We are now considering the large group of patients whose pain is constant, relentless and without such signs. A vascular basis for their disorder has not been proven.

Our own experiences with operations on roots or nerves more peripherally have been almost as unhappy as those of Drs. Grant and Glaser. We agree that many of the patients, although complaining bitterly when questioned, show little other evidence of suffering. In 20 patients in the last 15 years whose pain seemed especially severe and who had no obvious autonomic accompaniments, we have been led to a series of neurectomies and arteriectomies, usually futile, of the type mentioned in the table from Glaser. A tabulation of the facts in each would not be instructive. We have given details of two successes following sympathectomy. In our whole group a good result was obtained in only one other patient:

Mrs. Carolyn P. (M.G.H. #230379), aged 54 years, had had for 10 years attacks of pain lasting minutes to hours sometimes preceded by nausea. At times external stimuli seemed to bring on an attack. The pain in the early attacks was referred to the right upper and lower teeth and to the cheek; later it spread to include the whole right side of the face, head and posterior neck. The superior portion of the right trapezius was often sore. Ten years previously Dr. C. H. Frazier had carried out an intraoral injection, and nine years later Dr. W. Dandy had blocked the trigeminal third division with alcohol; neither procedure helped. Removal of teeth, two drainages of sinuses and a right radical mastoidectomy had all given no surcease. She was having attacks every three to four hours night and day when seen by Dr. W. J. Mixter in January 1940. He sectioned the greater and lesser occipital, posterior auricular and transverse cervical nerves; this stopped all of the pain in the anaesthetic areas of neck and scalp. The remainder of the pain disappeared after total trigeminal rhizotomy on Feb-

ruary 2, 1940. Complete relief has persisted through the 10 years of follow-up.

We have not been able to determine what distinguished the pain or the patient in our three successes from our many failures, but even these few good results make us hesitant to proceed to operations on the brain until peripheral surgical procedures have had a trial. We have added unsuccessful attacks on the greater superficial petrosal nerve and on the facial nerve to the operations on Glaser's table. Thus Erminia T. (case 33, Table XIII), whose facial pain persisted after total trigeminal rhizotomy, had pain in the appropriate area around cheek and eye when the greater superficial petrosal nerve was stimulated at operation. Division of this nerve gave her no relief, nor did it help Albina S. (case 40, Table XIII). For Evelyn P.'s (case 36, Table XIII) intermittent attacks of malar and orbital pain, which at first somewhat resembled tic douloureux, we carried out total trigeminal rhizotomy. The pain then became constant, continued after division of the external carotid artery and procaine blocks of the stellate ganglion and facial nerve. When stimulation to branches of the facial nerve exposed below the orbicularis oculi reproduced her pain, these branches were cut as they emerged from the anterior border of the parotid gland, but the pain recurred in a few weeks. In another patient in whom trigeminal rhizotomy and division of the external carotid artery had failed, Dr. Mixter's rhizotomy of nervus intermedius, most of the eighth and all of the ninth cranial nerves also failed.

Patient Ann G. (M.G.H. #660420) deserves a brief note because her description of pain was so similar to that of typical trigeminal neuralgia. Her severe paroxysms started and remained within the lower two divisions of left trigeminal. Earlier left trigeminal rhizotomies by Mr. Krynauw in Johannesburg (middle fossa), Dr. Adson in Rochester (middle fossa) and Mr. Dott in Edinburgh (posterior fossa) had long since given her total trigeminal anaesthesia, yet exposure to cold still brought a burst of pain. Paroxysms occurred during a procaine block: 1) of the left facial nerve yielding facial paralysis; 2) of the cervical sympathetic yielding a Horner's sign, and 3) of the C2 and C3 roots yielding anaesthesia of upper neck and scalp. But a needle inserted against the skull at the foramen ovale seemed to provoke the pain which was stopped briefly by alcohol injection here. At our exploration of the middle fossa it was found that the mandibular nerve had already been cut as it entered the foramen ovale. Intracranial resection of the inferior portion of the Gasserian ganglion and the attached maxillary nerve unhappily accomplished nothing.

e) Head traction: Cervical intraspinal operations: Raney (1947) has emphasized the possibility that this form of neuralgia is related to lesions in the cervical spine. He thought a mid- or lower cervical osteoarthritis

with degeneration of the intervertebral disc accounted for the pain in 51 of 54 patients. Traction on the head, usually with a halter, but with a Crutchfield tongs in two cases, tended to give relief, whereas downward pressure on the head increased the symptoms. In two of his patients with benign extramedullary tumours of the upper cervical spinal canal an atypical facial neuralgia was present. Removal of the tumours eliminated this pain as well as the usual signs of compression of the cord. He contends that many patients with protrusion of a cervical disc and segmental root pain have atypical facial neuralgia as the initial symptom. Both Spurling (1947) and Scoville (1947) deny that any of their patients with protruded cervical discs have had such facial pain, but Mayfield and Hunter (1952) have seen chronic severe facial pain stop after removal of a protruded disc in one patient, and of a bony spur in two others at the C6-7 level. Murphey (1952) also states that, after procainization of an emergent lower cervical nerve root, pressure on the disc at that level may cause pain in the occiput.

As we have mentioned, Hunter and Mayfield (1949) described patients whose attacks of facio-cephalic pain followed a wrenching injury of the neck, and in whom relief was obtained by avulsion of the greater occipital nerve or section of the second, or second and third, cervical posterior roots. In three patients with similar pain, but without antecedent history of trauma, i.e., patients with atypical neuralgia, these operations gave no relief.*

4. Intracranial Operations

Operations on the peripheral nerves and roots having so frequently failed, procedures on the brain have been tried. Sjöqvist (1948) has had two encouraging experiences in patients of this type treated by his bulbar tractotomy. Possibly the good result here is related to division of pain pathways entering via the seventh, ninth and tenth nerves, although he does not give accounts of his sensory examinations in these zones which would add data regarding this conjecture. In two other such cases he states that "the patients' condition was unimproved in spite of satisfactory analgesia." Erskine and Rowbotham (1949) also produced analgesia but failed to stop the pain in their patient of this type. Odom and Lyman

*Finlayson (1948) under the heading of "cervicogenic cephalalgia" has described a syndrome of unilateral pain extending from suboccipital to frontal and orbital areas in 74 patients. The autonomic phenomena of Horton's syndrome—ipsilateral lachrymation, conjunctival and nasal congestion—were seen in many of these patients. Hypalgesia was said to be present in the zone of the second or third cervical nerve root, and procaine block of the root so affected often relieved the pain in head and upper face. This author's ideas in this difficult field are still evolving and he has not yet published his work (personal communication, 1953).

(1946) failed to stop continuous burning pain in the left eye either by total section of the trigeminal root or by subsequent removal of the facial area in the postcentral cortex. Our depressing results following removal of orbital cortex have been set out in Table XIII (p. 312).

Unilateral prefrontal lobotomy on the side of a previously unsuccessful trigeminal rhizotomy stopped the original pain and the post-rhizotomy paraesthesias in two patients reported by Dickmann and Bielsa (1949). Wertheimer and Mansuy (1949A) had a potentially encouraging experience in their third case, a patient similar to our Ann G. with pain simulating trigeminal neuralgia, whose paroxysms did not stay relieved after trigeminal rhizotomy first in the middle and then in the posterior fossa. At the time of their report, four months after a right-sided lobotomy, she was free of pain, but similar periods of temporary relief had followed each of her rhizotomies. There is no justification for claiming success with this operation after such a brief period of observation, as our experience reported in Chapter X shows that pain nearly always returns after six months. The same authors (1949B, case 11) recorded total failure to help another patient with bilateral facial pains either by two bilateral frontal lobotomies or by a subsequent bilateral topectomy with the removal of 28 grams of brain.

Krayenbühl and Stoll (1950A and B), in their report on 10 patients treated for pain by operation on the frontal lobes, mention three with atypical facial neuralgia; one died a fortnight after contralateral leucotomy in the superior frontal quadrant; one showed apathy and loss of initiative along with absence of spontaneous complaints after bilateral frontal leucotomy; the third, after bilateral removal in the general region of areas nine and 10 also had relief of pain marred by behaviour disorders. After 20 months the apathy had largely disappeared, but the pain had returned. All three patients had previously had trigeminal rhizotomies. These authors conclude that leucotomy and topectomy should not be used in chronically ill patients, but should be reserved for those whose primary disease is likely soon to kill them. Scarff (1950) is much more sanguine about the value of his complete unilateral lobotomy. Of three patients with atypical facial or cephalofacial neuralgia, two no longer complained of pain even at 17 months, and the third had a "fair" result at five months. Lyerly (1951) is pleased with the results in patients with pain of his anteriorly placed bilateral frontal lobotomies. However, his two patients with atypical facial neuralgia had been followed only a few months at the time of his report.

Le Beau and Rosier (1949) and Le Beau (1950) have also been encouraged by their experiences with "topectomy" consisting of the removal of 10-12 grams of brain from the superolateral surface of each frontal lobe near the midline. Of 10 patients with a diagnosis of atypical facial or cephalic pain submitted to this procedure, nine showed good results at two

to 30 months, and only one was a complete failure. In a subsequent publication (1951), in which Le Beau does not report the result for each type of intractable pain, he gives a lesser proportion of successes—only two-thirds of a total of 45 cases.

Spiegel and Wycis (1953 A and B) have recently brought us up to date on the results in this disorder of their coagulations by electrodes placed in the dorsomedial nucleus of the thalamus and in the region of the mesencephalic pain pathways. Each of their five patients had had a previous retrogasserian rhizotomy, which in the first had given relief from apparent trigeminal neuralgia for 10 years. Then, despite right facial anaesthesia, "knife-like, excruciating attacks" recurred in the right eye and nose "as typically seen in cases of tic douloureux." In two of the patients lesions were made in the region of the contralateral dorsomedial nucleus of the thalamus and in the spinothalamic and quintothalamic tracts in the midbrain. The first of these has remained free of pain for four-and-a-half years, and the second has had only one burst of pain in four years, this despite only slight or moderate hypalgesia in the torso and limbs (the face was already anaesthetic from the previous root section). In the third patient electrical lesions were made in the region of dorsomedial, arcuate and lateral part of posteroventral thalamic nuclei. Contralateral hypalgesia of the body disappeared in two months and the pain in the face returned. At a second operation lesions were placed in both dorsomedial nuclei and in the region of pain pathways just caudal to the thalamus at the level of the posterior commissure. Although the patient no longer complained of her pain, she gradually became noisy and confused and died in three months. In the fourth patient previous operations had included a transorbital lobotomy which gave only temporary relief. Unfortunately Spiegel and Wycis' procedure has also been followed by recurrence. In their fifth patient, two previous trigeminal rhizotomies and their own mesencephalotomy gave no useful relief, but a subsequent combined mesencephalotomy and dorsomedial thalamotomy have succeeded for the few months since this operation.

To summarize this whole difficult problem one may say that *operations on peripheral pathways have but little chance of success. Trigeminal rhizotomy is nearly certain to fail unless there has been clear-cut relief following peripheral trigeminal injection with alcohol or neurectomy. Prior to embarking on a major operative procedure the surgeon had better rely heavily on psychiatric assistance,* as described by Dr. Cobb on p. 106 *If this proves unavailing and his patient is threatening to become a hopeless drug addict, his best recourse may then be a fractional lobotomy, partial removal of frontal cortex, or thalamo-mesencephalic coagulation.* The precise place of these three procedures will require further evaluation.

CHAPTER XVII

PAIN OF SPINAL ORIGIN

THE PAINFUL STATES discussed in this chapter follow injury or disease of the spinal cord, its dorsal roots, and the cauda equina. They develop as complications of trauma, adhesive arachnoiditis, tabes dorsalis, and herpes zoster. Pain in all these conditions may be a cause of severe and prolonged suffering, yielding to no form of medical therapy, and often driving the victim to drug addiction and at times to ultimate suicide. Relief of pain by neurosurgical methods is indicated when all other therapeutic measures have failed and before the patient's physical and mental health is undermined by prolonged introspection, dependence on narcotics, and chronic malnutrition.

A. RELIEF OF PAIN IN PARAPLEGIA

Prior to World War II, life expectancy following transection of the spinal cord or cauda equina was usually of short duration. The prewar studies of Donald Munro on the care of the paralyzed bladder, the development of successful means of combating sepsis and protein deficiency, plastic closure of bedsores, and the effective measures for general rehabilitation have opened up a new future for these victims. As a result it is no longer justifiable to continue medication with narcotics for the relief of pain. Pain, if allowed to persist, can destroy all hope of rehabilitation and even kill the victim through secondary malnutrition with the added complications that follow in its wake.

The incidence of persistent severe pain is somewhere in the region of 10 per cent, according to Kahn and Peet (1948). Freeman and Heimburger (1947) found that 45 of 600 paraplegic patients under their care required anterolateral cordotomy for its relief, an incidence of 7.5 per cent.

From experience with 190 cases of wartime spinal injuries in Naval Hospitals at Chelsea and St. Albans and the Cushing Veterans Administration Hospital, together with a single gunshot injury in a series of 23 cases of transecting injuries in civilians, we have seen eight patients that required neurosurgical relief, and have personally sectioned the spinothalamic tract in seven on whom adequate data are available. Judging from our own experience and the cases reported in the literature, it appears that persistent and severe pain is far more likely to complicate injuries of the cauda equina than of the cord itself. This is not surprising in view of the comparatively

greater length of sensitive posterior roots exposed in the lumbosacral canal. The pain, we believe, is caused by adhesions constricting these roots. It is also possible that pain may be produced by irritation of sensory fibres within the substance of the cord itself. We have been led to this conclusion by observing the sensitiveness of the posterior columns to mild tactile stimuli at the time of operation under local anaesthesia and the extensive invasion of scar tissue with inflammatory cells in the rostral stumps of two patients whose spinal cords were examined post-mortem after months of intense suffering (see Jeremiah O., p. 266, and James T., p. 312.).

The pain may be classified in four categories: viz., radicular, psychic, diffuse burning, and visceral (Davis and Martin, 1947). Patients with the



Fig. 122 Pain following injury and adhesions of cauda equina
Characteristic attitude of a patient with paraplegia and intense, unremitting pain following battle wound of the cauda equina; malnutrition, hypoproteinaemia, and indolent decubitus ulcer complicate the picture
Published with the kind permission of Dr. L. W. Freeman

first variety give a clear-cut description of intermittent sharp or aching pain which tends to follow patterns more or less associated with spinal dermatomes in which no objective sensation is present. If the pains are not too continuous these patients are willing to cooperate during pain-free intervals in the rehabilitation program, and may complain but little. When the pain is severe they assume a flexed position on the side and a drawn, utterly dejected expression (Fig. 122). All chances of rehabilitation may then be lost, as the patient becomes overwhelmed by his misfortune and loses his desire to eat. If the pain is allowed to continue, physical as well as psychical deterioration soon takes place from malnutrition, decubitus ul-

ceration, and loss of bladder-emptying reflexes. This type of radicular pain may respond to early division of the injured sensory caudal roots or, with far greater certainty, to spinothalamic tractotomy.

Psychic pain, on the other hand, permits less objective description. The patient tends to be cheerful enough when left alone with his friends, but makes innumerable vague complaints and requests for medication when visited by the doctor. Although uncooperative and difficult to rehabilitate, he is not likely to lose his appetite or general nutritional status, except slowly as a result of morphine addiction. Every effort must be made to exclude this group, as any neurosurgical procedure is certain to fail and may well make matters distinctly worse.

A third type of burning or "sympathetic" pain has also been described by Freeman and Heimburger (1947). According to them, "sympathetic pain is characterized by its constancy, by its dull, aching or burning nature and by its vague reference. . ." There is no relation to the spinal dermatomes, as seen in the pain of radicular origin. Davis and Martin (1947), who have given a detailed clinical description, postulate that the burning sensation may be related to pain fibres within the sympathetic trunks which enter the cord at a high thoracic level and pursue an upward course in the spinal cord outside the spinothalamic tracts. As evidence for this they cite a single case reported by Slaughter (1938) of paraplegia with a complete transverse injury at the level of the first lumbar vertebra. This man was relieved of his burning, prickling pain in both legs by bilateral resection of the lumbar sympathetic chains and hypogastric nerves. On the other hand, Freeman and Heimburger (loc. cit.) emphasized that sympathectomy is unlikely to succeed, since the typical burning sensation is often present in patients after complete interruption of sympathetic pathways to the lower half of the body. They stated that the pain was not eliminated in a single one of their five patients in whom sympathectomy was carried out in the hope of obtaining relief. If burning pain actually reaches the cord over the paravertebral sympathetic pathways, we would expect it to be interrupted by high thoracic cordotomy, as we have found this to be the case with pain from the abdominal viscera (see p. 584). We would therefore advocate cordotomy as the procedure most likely to relieve this as well as the better understood pain of radicular origin. Burning pain is often seen in the early stages after penetrating wounds of the spinal cord and cauda, but generally subsides with satisfactory general medical and psychiatric treatment. To be sure, this is not always the case. Davis and Martin have reported its persistence for as long as four years in a number of paraplegic patients and obtained poor results with spinothalamic tractotomy. They failed to state, however, how often an adequate level of analgesia was obtained. Freeman and Heimburger claim that the post-cor-

dotomy level of analgesia should extend to the fourth thoracic segment in order to cut off all incoming visceral impulses via the paravertebral sympathetic trunks. We are in complete agreement with the views expressed by these latter authors, save that we have not found it necessary to raise the level of analgesia quite as high as the fourth thoracic segment. In a patient with a caudal injury cordotomized by Dr. Thomas I. Hoen on White's service at the Naval Hospital at St. Albans (not included in Table XXXI), a sense of mild burning persisted in the legs after relief of his more severe aching pain that had required morphine and prevented rehabilitation. This cleared by degrees as his general condition and nutritional status improved. We have seen two other instances of burning pain on the paraplegia service at the Cushing Veterans Administration Hospital. Patient 3 failed to benefit, whether because of an inadequate sensory level from his cordotomy or from his neurotic constitution or other causes it is difficult to say. Patients 5 and 7, despite rather low levels of analgesia (T7 and T9), lost all sensation of burning, even though deep aching pain persisted in the latter for many months until his addiction to morphine was cured.

From the evidence reviewed above we doubt that the burning pain of this particular group of patients is related to the sympathetic nervous system. Furthermore, we have been unable to produce any sensation of this sort by direct stimulation of the splanchnic nerves or lumbar ganglia in conscious patients under local anaesthesia. We therefore agree with Freeman and Heimburger that pain of spinal injury is caused only by irritation of "the contents of the spinal canal and efforts aimed at the periphery disregard the seat of the pathological changes." Provided the injury involves the cauda equina and does not extend rostrally beyond the conus medullaris to involve the cord, we believe that relief can be obtained in a high proportion of cases by anterolateral cordotomy.

True visceral discomfort is occasionally seen after injury to the cord or cauda equina. As pointed out by Davis and Martin, this is in no wise related to "burning pain," but consists of vague sensations such as "fulness in the abdomen related directly to distension of the urinary bladder or cramping, vague, diffuse, periumbilical and hypogastric pains which occurred when the patients received enemas . . . Many of the patients had a feeling of nausea, sudden profuse sweating, flushing of the face, headaches, and pilomotor reactions." These sensations are often observed, but rarely cause sufficient complaint to require surgical intervention. Dr. E. H. Botterell (personal communication) described a case of gunshot injury to the conus with low abdominal pain coming in severe attacks, ashen pallor, and profuse sweating. Sympathetic ganglionectomy gave no relief, but the painful episodes ceased after bilateral spinothalamic tractotomy with a T5 level. We

have tried sympathectomy in a single case of pure visceromotor disturbance without pain. This soldier complained of chilling and local drenching perspiration in his flank each time his bladder filled. The larger portion of the area over which his clothes were soaked has remained dry and comfortable following an extensive paravertebral resection of his lower thoracic sympathetic ganglia. More recently Kendrick, Jousse, Scott, and Botterell (1951) have reported successful results from intrathecal injection of alcohol in three other patients with these symptoms accompanied by reflex rise in blood pressure and also flexor contractions of the legs. Bors and French (1952) have also pointed out that many of these peculiar sensations, such as the headache that may accompany distension of the bladder or an enema, are related to exaggerated reflex vasoconstriction and episodes of hypertension. In a number of their patients these episodes were so severe that surgical intervention became necessary. For this they recommend interruption of the viscerosensory reflex arc by sectioning the posterior roots of the lumbosacral plexus in preference to destruction of the motor arc by thoracolumbar sympathectomy.

Freeman and Heimburger (1947) have had an unusually large experience with painful complications in 600 spinal injuries treated during the war and at the Kennedy Veterans Administration Hospital in Tennessee. Pain was a complicating factor of such severity that it necessitated operation in 58 patients, with section of the spinothalamic tract in 45. In this group the pain was abolished in 34, improved in nine, and unaltered in only two. In Kahn and Peet's (1948) smaller series 11 out of 12 were relieved over a follow-up period of five months. In a recent additional series of 11 cases of cauda equina injury from the Kennedy Veterans Administration Hospital, DeSaussure (1950) reports consistently effective relief following anterolateral cordotomy in the entire series. In another series of 10 cases reported by Kuhn (1947) seven successful results were obtained, with failures only in two individuals in whom analgesia failed to reach the mid-thorax, and in a third with injury to the midthoracic portion of the cord. In four others reported by Botterell *et al.* (1946) all were "well pleased and grateful" for the relief obtained.

Conclusions drawn from our series confirm reports that *spinothalamic tractotomy will relieve somatic pain following injury to the cauda equina, provided a mid thoracic level of analgesia is achieved and maintained.* Many other surgeons have been pessimistic about the results of this operation, but in all the failures we have observed the level of complete loss of painful sensation was never sufficiently high, often barely a segment or two above the level of injury. Frequently the incision in the cord had been made too low (T3 to T5) to give the surgeon his best chance.

In the early stage of spinal injury, especially the penetrating variety due

to missiles, patients with pain should be submitted to decompressive laminectomy with local exploration and lysis of adhesions at the severed end of the cord or cauda equina, together with excision of the scar and damaged posterior roots. Early pain is often relieved by this procedure. Even in the late stage of chronic pain local operation deserves a trial if it has not been attempted before, but this is less likely to succeed than during the early period.

In patients who have failed to respond to decompressive laminectomy and general measures directed at physical and psychical rehabilitation, we are convinced that many surgical measures such as sympathectomy, peripheral neurectomy, subarachnoid injection of alcohol, and even extensive division of posterior caudal roots are unlikely to succeed. Each ineffective operative procedure is certain to set the patient back physically as well as to lower his morale. For this reason we recommend early recourse to cordotomy unless the lesion involves the cord proper (see below).

Even for pain in the legs and lower abdomen the spinothalamic tract should be severed as high as the first or second thoracic segments and to a depth of 5 mm., with transection of practically the entire anterolateral quadrant of the cord. This is usually easy in cases of complete transverse injury, as the cord is shrunken. Provided the dentate ligaments are cut on both sides, it can often be rotated a full 70 to 80 degrees to expose the anterior spinal artery. If, as is usually the case, the complaints are bilateral, the pain pathway must be cut on each side, staggering the incisions at least a vertebra apart to preserve local circulation of the cord. In this group of cases there is no advantage in performing the bilateral operation in two stages, as the cordotomy can have no deleterious effect on vesical function. The operation should be performed under local anaesthesia, supplemented by a light stage of Pentothal and with additional inhalation of nitrous oxide or Trilene until the preliminary incision in the cord has been made. Individuals anaesthetized in this manner should be sufficiently awake and cooperative for testing within five to 10 minutes. We believe that verification of the level of analgesia is of vital importance, as the first incision in our experience is rarely adequate. In our single failure (Patient 3) satisfactory testing of the sensory level could not be carried out.

Our cases are summarized in Table XXXI None of these men noticed any change in bladder control or other untoward complications. Because of the risk of possible motor weakness we have hesitated to incise higher segments of the cord in individuals who are so dependent on the use of their upper extremities. A properly performed deep incision at T1 or T2 should suffice, but it is essential to test its effect at the time of operation and not to trust one's eye or the depth marker on the cordotomy knife.

The report of Freeman and Heimburger (1947) differs from our experience only in the statement that the sensory level must be brought as high as T3 for universal success. In our series, as mentioned above, satisfactory results have occasionally been obtained when analgesia has risen only to much lower levels, provided it has been complete (T9 in Patient 7 and L1 in the exceptional instance of Patient 2). Levels as low as this, however, are not sure to succeed, as exemplified by Patient 3, in which analgesia to the umbilicus proved insufficient.

Many of the neurosurgeons serving in military hospitals during World War II and in Veterans Administration Paraplegic Centres have failed to achieve adequate levels or, if initially successful, the level of analgesia has sometimes fallen and the pain recurred. This is the reason for so many reported failures, even in cases of cauda equina lesions where the pain involves only the lower abdomen and legs. From reference to Table XXXI it will be seen that three out of our six military patients required secondary interruptions of the spinothalamic tract after previous unsuccessful attempts at other hospitals. This is illustrated by the following case history:

> *Patient 5,* John L., 23: Following a shell fragment wound over the first lumbar vertebra received in August, 1944, there had ensued complete flaccid paralysis complicated by severe and persistent pain. He had been submitted to three operations, consisting of an early exploratory laminectomy and two previous cordotomies performed much too low in the back (T5-6 and T3-4). For a few days after the second attempt his analgesia had extended up as high as the eighth rib and his suffering was briefly relieved. His old aching and shooting pains in the testicles, knees, and feet soon recurred as the sensory level fell to the lower abdomen. When we cut the pain tracts more deeply in the uppermost thoracic segments and raised the level of analgesia to T7, with hypalgesia to the nipples, his pain disappeared and he has remained free of it for over a year.

When the injury which causes pain involves the cord itself and higher thoracic segments are involved, it is still a question whether relief can be obtained by cordotomy. Davis and Martin (1947) claim that this is impossible. Theoretically, it is difficult to see how injured pain fibres above the totally severed proximal stump can survive to respond to local stimuli, as their cells of origin lie in the posterior horn of grey matter caudal to the level of transection. Because the rostral portion of the lumbosacral fibres in the spinothalamic tracts (and also in the posterior columns) must degenerate, one is led to wonder how pain can be referred to any point below the level of injury. Observed facts, however, must always take precedence over theory and it is possible that intact pain fibres in the ascending tracts are irritated by the scar.

Two of our cases in Table XXXI had complete functional interruption of the lower segments of the spinal cord, with paralysis extending to the ninth thoracic segment in Patient 1, and in Patient 6 a lesion verified at previous exploration at the eleventh thoracic vertebra. Both of these men required narcotic medication in large amounts, and the former was so tortured by his pain that his weight was reduced to 100 pounds and we feared he would die of malnutrition. The effect of anterolateral cordotomy in both was dramatic and unquestionably the factor that made recovery possible in the first. Inasmuch as the exact site of injury to the cord was never established in this officer, we cannot draw any conclusions from this experience. Two other patients with persistent pain referred to the legs from midthoracic lesions of the cord obtained no relief, despite satisfactory sensory levels. These operations were performed by other surgeons against our advice and are therefore not included in our table.

We have seen two patients with total destruction of extensive portions of the middle and upper thoracic segments of the spinal cord in which the scarred rostral stump was resected to a point well above the obvious scar. Neither had a significant improvement in his symptoms, and ultimate postmortem examination showed that intrinsic fibrosis of the cord extended well above the level of resection. The second of these unfortunate individuals was subsequently relieved by a resection of his left supraorbital cortex, but developed an abscess in his frontal lobe, to which he succumbed (see p. 317, James T.).

Freeman and Heimburger give no data in their paper on the level of injury in their 45 cases relieved by cordotomy, although they observed that complete injuries above the third thoracic segment never produced pain referred to the viscera or lower extremities. In answer to a written inquiry Dr. Freeman states that in five of his patients the injury involved the tenth, eleventh, or twelfth thoracic segments of the spinal cord, and all obtained satisfactory relief with high levels of analgesia. The pain recurred in only one, in whom the sensory level fell.

From these statistics we feel that Davis and Martin's observations are unnecessarily pessimistic and that *pain, even when it follows injuries to the lower segments of the spinal cord, can be relieved, at least in the majority, by high and radical incision of the anterolateral quadrant. The chances of success, however, are certainly less favourable than in injuries limited to the cauda equina.* With lesions situated above the conus medullaris and uppermost inflow of the cauda equina, the operation is probably unlikely to succeed. Fortunately severe persistent pain is rare in lesions of the cord proper.

TABLE XXXII

ANTEROLATERAL CORDOTOMY IN THE TREATMENT OF ARACHNOIDITIS WITH PERSISTENT PAIN (11 CASES)

Patient	*Age*	*Cause of Arachnoidal Adhesions*	*Pain*	*Other Operations at M.G.H. and Other Hospitals*	*Date*	*Cordotomy* *Level*	*Side*	*Analgesia*	*Result*
1. Oscar J. MGH U-158593BM Dr. W. J. Mixter	42	Trauma with hypalgesia below T7. This progressed spontaneously to nearly complete loss of sensation.	1½ yrs pain in lower back with radiation to groins and legs, *especially on R.*	6/40: Exploratory laminectomy and posterior rhizotomy T10-T12, R.	. . . .	. . . .	. . . .	. . . .	Nil.
					7/41	T3*	L.	T8	Relief for only 1 mo., then fall in sensory level.
				11/41: Posterior rhizotomy T3-T9, R.	. . . .	. . . .	. . . .	. . . .	Temporary relief only.
				6/42: Anterior rhizotomy T1-T10, R.	. . . .	. . . .	. . . .	. . . .	No better at 9 mos.
2. William D. MGH U-255414BM Dr. W. J. Mixter	42	6/38: Twisted back while bowling and had spinal epidural haemorrhage. 1/39: Epidural mass removed at another hospital.	L. back, testicle and leg with fasciculation and motor weakness. *Pain in L. groin* and testicle.	7/40: Exploration of cauda equina, lysis of adhesions, posterior rhizotomy T12-L2, left.	. . . .	. . . .	. . . .	. . . .	Worst pain in L. leg relieved.
				11/41: Section ilioinguinal nerve.	. . . .	. . . .	. . . .	. . . .	Nil.
					11/42	T2*	R.	T8	Complete relief at 8 mos.
3. Caroline S. MGH U-147691 Dr. W. J. Mixter	68	Sciatica since 1931 of spontaneous origin. Pt. has 6 lumbar vertebrae with added osteoporosis and degenerative arthritis.	Continuous pain in lower back and *R. sciatic* distribution.	R. sacroiliac fusion. 1941: Removal herniated *disc complicated by post*-operative sepsis.	3/43	T2*	L.	T6	6 yrs. postop. complained of some pain on prolonged standing in R. leg, weak from disease; also some deep paraesthesia. Former severe continuous pain is gone.

Table XXXII

ANTEROLATERAL CORDOTOMY IN THE TREATMENT OF ARACHNOIDITIS WITH PERSISTENT PAIN (11 CASES)—Continued

Patient	Age	Cause of Arachnoidal Adhesions	Pain	Other Operations at M G H and Other Hospitals	Date	Cordotomy Level	Side	Analgesia	Result
4. John C. MGH U-588130	41.	Fall with fracture of lumbar vertebra, 1932, but without sequelae for 14 yrs.	Persistent pain in legs, especially L., with atrophy and muscular weakness.	10/46: Removal protruded intervertebral disc at L4 Lysis of adhesions on 3 occasions and 4 attempts at *cordotomy at another clinic.*	. . .	. . .	. . .	. . .	Nil.
					. . .	. . .	. . .	. . .	Hypalgesia to T7, analgesia only to L1.
					2/48	T1*	R.	T12	Pain relieved at 2 yrs. but spinal disease progressing to paraparesis.
5. Elmer R. MGH U-612840	44	*Multiple operations in* 1943 and 1944 for intervertebral disc at L5 interspace. Subsequent fracture of L5 articular facet followed by spinal fusion.	*Pain in lower* back with radiation to L. groin and buttock persisted for 4 yrs. following fusion.	5/44: Section of adherent S1 spinal root.	. . .	. . .	. . .	. . .	Nil.
					5/48	T2*	R.	T8	Complete relief at 2 yrs.
6. Helen L. MGH U-440003BM	62	After removal of neurofibroma pain steadily increased in severity. Could sleep only in chair. Had residual weakness of legs and atonic bladder before cordotomy.	Sacral pain radiating down both sciatic nerves.	3/44: Resection of neurofibroma from cauda equina.	5/3/48	T1*	L.	T8	
						T2	R.	L2	
					5/25/48	T2*	R.	T7	Free of pain at 10 mos. but restricted *to quiet* life because of weak legs.
7. Hamilton I. MGH U-629098BM	63	Low back pain for many years Mild injury to cervical cord in 1930.	Burning sensation developed in 1944 in buttocks, perineum and testicles with bilateral sciatic radiation, worse on L., also difficulty in urination and impotence for 2 yrs.	Previous exploration for disc at another hospital. 8/48: Exploratory laminectomy which revealed lumbar arachnoiditis.	10/48	T4*	R.	T7	Pain relieved in L. leg but not in lower sacral dermatomes. Urination improved after transurethral resection for prostatic hypertrophy. 11/48: R. frontal leucotomy performed by Dr. J. E. Scarff with considerable *benefit* but pain had re- [illegible]

8. Henry H. MGH U-503185	34	Two previous excisions of bilateral protrusions of intervertebral discs followed by spinal fusion.	Recurrent pain for 17 mos. after strain from lifting heavy weight. Pain unbearably severe on L. Subsequent increase of pain on R. side.	7/48: Partial removal bone graft, laminectomy L4 and exploration. No evidence of recurrent disc herniation, but severe arachnoidal adhesions.	10/48 3/51	T2* T3*	R. L.	T7	No complications and excellent result at 45 mos. Equally good result with little urinary difficulty.
9. Sara B. MGH U-487628	60	Multiple laparotomies under spinal anaesthesia. Pain, with perineal numbness and incontinence, after first laminectomy (not under spinal).	Severe persistent pain in low back, gluteal region and legs with burning sensation in perineum.	Two laminectomies with spinal fusion for spondylolisthesis. Re-exploration and lysis of extradural scar.	10/49	T2*	R.	T9	This patient like Case 7 had no relief of the burning rectal pain. Was later improved by unilateral frontal leucotomy, but pain gradually returned.
10. Matthew B. MGH U-647982	43	*Auto accident in 1936* with injury to lumbar vertebrae and later arthritic spondylitis.	Gradual increase of pain in lumbar spine and legs, increased by any movement.	1/49: Osteotomy at T12-L1. Postoperative subluxation with cord compression required second operation. 6/49: Re-exploration for arachnoiditis.	9/49 10/49	T2* T3*	L. R.	T10 T10	Relief of former pain on movement of legs, but he soon developed ascending spastic paraplegia with reflex contractions of legs and intense pain in tight muscles. Died in 8 mos.
11. G. S. MGH U-751178BM	32	Airplane accident in 1942 with severe low back injury and fractures of L1 and *L5 vertebrae.*	Incapacitating pain for 8 yrs. in R. buttock, thigh and leg accompanied by muscular weakness.	Two resections of desmoid tumour in R. flank. Exploratory laminectomy and section of thickened L5 spinal root.	9/51	T2*	L.	T7	Eight mos. later was playing strenuous games and planning return to army aviation. Full activity at 2 yrs.

*Testing of sensory level at time of operation.

B. ARACHNOIDITIS

Arachnoidal adhesions may result from such obvious lesions as focal infection, injuries to the vertebrae, or penetrating wounds of the dura. This complication may also develop after surgical removal of protruded intervertebral discs and tumours of the cauda equina. Recently Kennedy *et al.* (1950) have called attention to the fact that crippling adhesions may follow spinal anaesthesia. When the adhesions involve the cauda equina the resultant radiculitis may be a cause of unremitting pain as well as weakness of the legs and bladder. The cases of direct traumatic origin are included in the previous section on spinal injuries. Those about to be described are due to other causes. Etiology, symptomatology, and pathology have been discussed by French (1946).

Four of the 11 cases summarized in Table XXXII followed closed injuries of the vertebral column. The others developed as complications of multiple spinal operations: for actual or supposed intervertebral disc protrusions in five, spinal fusion for spondylolisthesis with complicating injury to the caudal roots in another, and removal of a large neurofibroma with some of its capsule left adherent to the caudal roots in the seventh. In two the arachnoiditis was complicated by severe arthritic changes.

From inspection of this table it is obvious that neither lysis of adhesions nor section of posterior roots has much to offer in the control of pain. Lysis of arachnoidal adhesions is followed by early reformation, just as is the case with peritoneal bands. A great many roots are usually matted together, and even such an extensive rhizotomy as in Patient 1 (T3-T12) is likely to fail. Because of the fact that certain German and British reports (Lehmann, 1924B; Foerster, 1927A; and Shaw, 1933) ascribed the failure of posterior rhizotomy to conduction of pain over anterior roots, division of these structures was finally undertaken by Dr. W. J. Mixter in this patient. No benefit resulted.

A preliminary trial of posterior root section is justified only at the time of the primary laminectomy when the diagnosis of arachnoiditis is established. Extensive lysis of adhesions and division of the most severely involved sensory roots is a logical enough procedure at this time, but the surgeon should resist the temptation to extend the primary laminectomy and sever further roots after an early partial success. The pain is nearly certain to recur, and the condition is then exaggerated by the added mechanical weakness of the spinal column with the superimposed deterioration of morale that follows all ineffective surgical procedures. The following case histories illustrate these points in a striking way:

Patient 4, John C., MGH U-588130, 41: This patient fractured his second lumbar vertebra in a fall in 1932, without any evidence of nerve damage

or accompanying pain. He was then well and able to work until two years prior to admission, when he strained his back while lifting heavy luggage. He "felt something give" and this was immediately followed by constant non-radiating pain in his lower back. In addition to low backache and right-sided sciatica, he began to complain of pain in his left leg and foot. He was at first treated for rheumatism, then ruptured intervertebral disc was diagnosed and he was referred to one of the leading neurosurgical clinics in the country. There he underwent the following series of operations:

1) 6/6/46: Laminectomy L1-L3 with lysis of arachnoidal adhesions.

2) 10/5/46: Exploration of L4 and L5 interspaces on right side with removal of protruded discs.

3) 11/9/46: Right anterolateral cordotomy at T3.

4) 2/18/47: Extradural exploration T12 to L4 with removal of a pseudomeningocele and scar.

5) 3/6/47: Intradural exploration with further lysis of adhesions.

6) 3/19/47: Secondary spinothalamic tractotomy at T5 on right. At this time he was reported to have a partial level of analgesia to T7, and to have had considerable improvement in his left leg pain, although his ankle still hurt. He was complaining of increasing pain in the right leg, and his next hospital admission was precipitated by an overdose of barbiturates.

7) 5/26/47: Left anterolateral cordotomy at T4. As he still complained of pain and had no sensory level, the operation had to be repeated.

8) 6/14/47: Secondary left cordotomy at T5 with partial improvement of pain in the right leg.

When admitted to the Massachusetts General Hospital in February, 1948, he was bedridden because of pain in his back and left leg, which prevented any activity. There was pronounced atrophy of the muscles in this leg, difficulty in urination, and he was 40 pounds underweight. Both legs were weak and both knee and ankle jerks were absent. Although there was reduced sensation to pinprick to the costal margin on each side, there was actual analgesia only in the distribution of the left sacral dermatomes.

As most of his residual pain was in his left leg, and his previous cordotomies had been performed at a rather low level and were obviously incomplete, a radical transection of the right lower quadrant of his spinal cord was carried out on 2/24/48 at T1 under local anaesthesia. Although hypalgesia was easily obtained to the nipple line, even repeated deeper cuts failed to secure complete analgesia above the umbilicus. The patient made an uneventful convalescence except for persistent difficulty with an atonic bladder. He was able to void spontaneously as before, but carried a large amount of residual urine.

Eight months later the patient remained free of pain on his left side. He had gained weight, looked healthier, and was able to be much more active. Although he had mild residual discomfort on the right, he graded himself as 80 per cent better. He had hypalgesia to the nipple line on the left side, which many casual observers would have graded as complete loss

B. ARACHNOIDITIS

Arachnoidal adhesions may result from such obvious lesions as focal infection, injuries to the vertebrae, or penetrating wounds of the dura. This complication may also develop after surgical removal of protruded intervertebral discs and tumours of the cauda equina. Recently Kennedy *et al.* (1950) have called attention to the fact that crippling adhesions may follow spinal anaesthesia. When the adhesions involve the cauda equina the resultant radiculitis may be a cause of unremitting pain as well as weakness of the legs and bladder. The cases of direct traumatic origin are included in the previous section on spinal injuries. Those about to be described are due to other causes. Etiology, symptomatology, and pathology have been discussed by French (1946).

Four of the 11 cases summarized in Table XXXII followed closed injuries of the vertebral column. The others developed as complications of multiple spinal operations: for actual or supposed intervertebral disc protrusions in five, spinal fusion for spondylolisthesis with complicating injury to the caudal roots in another, and removal of a large neurofibroma with some of its capsule left adherent to the caudal roots in the seventh. In two the arachnoiditis was complicated by severe arthritic changes.

From inspection of this table it is obvious that neither lysis of adhesions nor section of posterior roots has much to offer in the control of pain. Lysis of arachnoidal adhesions is followed by early reformation, just as is the case with peritoneal bands. A great many roots are usually matted together, and even such an extensive rhizotomy as in Patient 1 (T3-T12) is likely to fail. Because of the fact that certain German and British reports (Lehmann, 1924B; Foerster, 1927A; and Shaw, 1933) ascribed the failure of posterior rhizotomy to conduction of pain over anterior roots, division of these structures was finally undertaken by Dr. W. J. Mixter in this patient. No benefit resulted.

A preliminary trial of posterior root section is justified only at the time of the primary laminectomy when the diagnosis of arachnoiditis is established. Extensive lysis of adhesions and division of the most severely involved sensory roots is a logical enough procedure at this time, but the surgeon should resist the temptation to extend the primary laminectomy and sever further roots after an early partial success. The pain is nearly certain to recur, and the condition is then exaggerated by the added mechanical weakness of the spinal column with the superimposed deterioration of morale that follows all ineffective surgical procedures. The following case histories illustrate these points in a striking way:

Patient 4, John C., MGH U-588130, 41: This patient fractured his second lumbar vertebra in a fall in 1932, without any evidence of nerve damage

am enjoying very good health—wonderful, isn't it, after those long years of complaining of pain?—and really feel fit as a boy of 20 years old." He was requesting immediate return to his flight duties. At last accounts in January, 1954, he was active as a high official in the Egyptian government.

It is evident from Table XXXII that our attempts to relieve the pain of adhesive archnoiditis by cordotomy have been distinctly less successful than with other varieties of chronic pain not associated with malignant disease. The results have been unqualifiedly successful in only seven of the 11 patients operated upon. In Patient 10 the original symptoms were relieved and this arthritic cripple was enabled to move his legs again, only to have the process ascend to involve the cord with a secondary development of mass flexion contractions. These gave rise to cramping pain in the muscles in his legs. As we have pointed out on p. 267, the pain of muscle cramps cannot be relieved by cordotomy. Failure was complete in Patients 1, 7, and 9; in the first because of inadequate transection of the anterolateral quadrant, in the other two because cordotomy failed to relieve burning perianal discomfort. We have likewise failed to relieve this complaint on another occasion (see Patient 32, Table XLII in Chapter XVIII, in which this troublesome symptom accompanied ovarian carcinoma).

It must be pointed out, furthermore, that the surgeon is likely to encounter an unusual number of disappointments and complications in his attempts to relieve persistent pain in this condition. The proportion of urinary complications is high because of pre-existent paresis of the sacral nerves (Patients 4 and 7). As the disease tends to progress to involve the cord, these individuals may develop spastic weakness of the legs and flexion contractions (Patient 10). We have no explanation for the failure of the operation to relieve burning perianal and perineal pain, which was such a troublesome complaint in Patients 7 and 9. Because of the fact that pre-existent damage of the lower sacral nerves had already impaired control of the bladder, a further cordotomy on the opposite side did not seem justified. Both of these patients continued to suffer so severely that they subsequently required unilateral frontal leucotomies. The first was transferred to Dr. J. E. Scarff and was one of the early cases in his series. Re-examination by Dr. F. L. McNaughton and one of us revealed continuance of objective improvement at 17 months. At this time he required no narcotics and appeared to be enjoying the companionship of his wife and friends more than at any time since the onset of his illness, but subsequent letters stated that after three years he was again suffering severely. The second, Patient 9, was very apathetic with little affect in the early months, but later recovered her normal emotional state. She remained distinctly more comfortable at the end of a year, but like Patient 7 her original discomfort gradually returned to its former severity.

of pain sensation. Actually, however, analgesia was complete only to the first lumbar dermatome. The residual bladder disturbance, which was due in large part to disease of the caudal roots, was much improved by transurethral resection of the bladder neck.

At the last report, two years after his last operation, he was entirely free of pain, but his arachnoiditis had increased and extended upwards, so that he was analgesic on both sides to the fifth thoracic level. His legs had gradually become too weak to carry him and urinary incontinence had developed to the extent that he had to wear a rubber urinal.

Patient 11, G. S., MGH U-751178 PH, 32: This officer in the Egyptian Air Corps suffered extensive injuries when his plane crashed in flames during the Libyan campaign of 1942. In addition to severe cerebral contusion and superficial injuries, fractures of both legs and one arm and a haematoma of the right hip, there were fractures of the body of the first lumbar and of the transverse process of the fifth lumbar vertebra. He made a surprisingly good recovery save for residual diplopia and pain in the right hip. The area of the haematoma soon developed a "desmoid" tumour, which was removed in 1946 and treated by heavy radiation. Despite this the tumour recurred. At reoperation in England by Mr. Stanford Cade, after ligation of the iliac artery, the tumour was again removed, this time without recurrence. The pain, which had involved his lower back, right hip, and sciatic distribution from the time of injury, was not relieved. Mr. Geoffrey Knight then did an exploratory laminectomy, finding a fracture of the fifth lumbar lamina with its foramen filled with bone and the emerging spinal root compressed. The sensory root was cut, but without any effect on his pain. He then consulted Mr. D. W. C. Northfield in London and Dr. W. McK. Craig at the Mayo Clinic, who advised cordotomy, but for fear of weakening his normal left leg he had been reluctant to have this done.

At our examination the patient was tender over his right sacroiliac joint, buttock, and lower lumbar vertebrae. There was slight weakness of the muscles in his right leg. Sensation was reduced in the lower sacral dermatomes. As there was no evidence of recurrent tumour and his pain antedated its appearance, we told him that this was undoubtedly due to arachnoiditis and could only be relieved by cutting the spinothalamic tract.

A wide transection of the left anterolateral quadrant at T2 was carried out on 9/11/51. On sensory testing the patient was most cooperative. After the first incision analgesia rose to T12 and following a second, deeper, and more ventral section to T7. He voided normally within a week and made a good convalescence without any muscular weakness or other complaints. When last examined two months later analgesia was complete in the sacral dermatomes, while above this level he had some awareness that rapid pricking of a pin had some qualitative difference from blunt pressure, although it was not painful below the xyphoid. Eight months after operation he wrote that he remained entirely free from pain and was able to take part in sports for the first time since his plane crashed ten years previously. "I

of the posterior rootlets as the site of the major lesion in tabes, so that one would not expect an operation peripheral to the posterior root ganglia to accomplish much. Tabetic lesions are also found independent of ascending degeneration in the posterior columns, as well as in anterior gray matter of the spinal cord. These intramedullary foci plus the widespread entry into the cord of innervation of the abdominal viscera may account for the failures from posterior rhizotomy. Exner (1911) tried bilateral subdiaphragmatic vagotomy in the hope that reduction of peristaltic activity might reduce the severity of gastric crises. Foerster, as well as Van Bogaert and Verbrugge (1928) and Grimson, Hesser, and Kitchin (1947), reports an uninterrupted succession of failures from bilateral vagotomy. One of the two patients of the last-named authors developed such a high degree of gastric retention that a secondary gastro-enterostomy was necessary. We now feel that *no neurosurgical procedure short of anterolateral cordotomy is worth consideration.* This operation, first performed for this disorder by Tietze at Foerster's suggestion, offers fairly reliable hope of success provided, as is so often emphasized in this book, the level of analgesia be carried to and remain at a sufficient height.

The effectiveness of adequate division of the anterolateral pain tract was predicted in Foerster's (1927*B*) initial account. He performed this operation 11 times for painful gastric crises with nine successful results initially. Recurrence of pain in one patient eight months after operation was correlated with return of deep pain and of temperature sensation, although cutaneous analgesia persisted up to T1 and T2 segments on the two sides. The two early failures each had their bilateral incisions at the T4 and T5 segments. In one of these the analgesia was grossly inadequate; in the other the analgesia extended up to T6 level—a fact which led Foerster to hypothecate the entry of some abdominal visceral pain fibres into the cord above this level. Kahn and Barney (1937) have reported 12 cases in which the anterolateral incision was carried "at least 2 mm. beyond the emergence of the anterior nerve root." Its effectiveness was thereby increased to 10 successes out of 12, with one death, due to the patient's extremely poor [illegible] recession of the sensory level. [illegible] cordotomy, performed at the fifth thoracic level, is instructive. The patient's pains, which radiated to the upper epigastrium, were not relieved by an analgesic level at the umbilicus. Subsequent bilateral sympathetic ganglionectomy and splanchnicectomy carried out above the diaphragm by Dr. Peet likewise failed, but a later incision of the anterolateral tracts to a depth of 4 mm. at the eighth cervical segment was finally effective.

Hyndman and Jarvis (1940), in addition to an excellent review of the literature and accounts of previous failures with other procedures, have

From our experience summarized above it seems reasonable to conclude that *radical transection of the anterolateral quadrant of the cord will usually relieve uncomplicated low back and sciatic pain in arachnoiditis of the cauda equina just as successfully as after traumatic injuries of this region. The analgesia must remain complete and include a number of spinal segments above the uppermost reference of pain. If the condition ascends to involve the spinal cord and flexion contractures develop, cordotomy will not relieve the painful muscular tension.*

C. TABETIC CRISES

Once the patient with neurosyphilis develops tabetic crises, even the most intensive forms of medical treatment have but little palliative effect. The gastric crises with vomiting and abdominal pain and the crises with lightning pains in the limbs may become so severe that they interfere with eating and sleeping. Unless relieved the sufferer is nearly certain to become addicted to analgesics, complicated by serious malnutrition and ultimate mental deterioration. Foerster (1927A, pp. 295-297) pointed out that it is only those patients with gastric crises characterized by frank abdominal pain and often accompanied during the attack by abdominal cutaneous hypersensitivity who are suitable candidates for neurosurgical procedures at the spinal roots or in the spinal cord. He described two other less frequent types of gastric crises: (1) the "vagal" form distinguished by persistent nausea in which pain appears only secondary to repeated retching and vomiting, or in relation to other structures with vagal innervation such as ear, larynx, or heart; (2) the "phrenic" form with nausea, pain and hypersensitivity in the shoulder and neck, with hiccoughs. No reports are available on the value of section of vagal rootlets or of rhizotomy at C3-5 respectively in the treatment of patients in these two latter groups.

The serious predicament of the unfortunates in the first category, in whom pain is in the foreground, is a challenge to neurological surgeons. Foerster (1927A, pp. 286-299) found that section of progressively increasing numbers of posterior roots up to T5-T12 for gastric crises yielded many failures interspersed with some successes. He was especially discouraged when lightning pains in one patient confined to an external malleolus continued despite posterior rhizotomy at lumbar 4 and 5 and sacral 1 levels. He also tried cutting both anterior and posterior roots from T5 through T10 for gastric crises in two patients, only one of whom obtained relief. The even more disappointing results of various forms of sympathectomy have been thoroughly reviewed by Foerster and by Hyndman and Jarvis (1940). As the former mentions, the histologic evidence points to the entrance zone

TABLE XXXIII

ANTEROLATERAL CORDOTOMY FOR RELIEF OF TABETIC CRISES (7 CASES)

Patient	*Age*	*Symptoms*	*Previous Operations*	*Date*	*Level of Cordotomy*	*Side*	*Sensory Level*	*Complications*	*Result*
1. Joseph M. MGH U-27159 Dr. J. S. Hodgson	43	L. abdominal crises for 10 yrs. Attacks lasting 3 to 4 wks. with sense of fulness of L. abdomen "as though stomach would burst." Cramps, eructation, nausea, vomiting Severe morphine addiction.	1. Procaine block coeliac plexus. Relief for 1 d. 2. Alcohol injection L. splanchnic nerve. Relief for 2 wks. 3. Ganglionectomy L1-L2 and L. splanchnicectomy. Relief for 2 mos.	1/35	T1*	R.	T6	None.	Returned to former work as waiter after 3 yrs. incapacity. Complete relief at 26 mos.
2. Pauline W. MGH U-54521	57	Shooting pains L. leg with bouts of vomiting for over 15 yrs. Required morphine 2-3 i.d.	None.	10/36	T2	R.	T5	R. hemiparesis and aphasia, which cleared rapidly.	Complete relief at 8 mos.
3. Mabel B. MGH U-108621 Dr. J. J. Michelsen	57	Leg and abdominal crises, chiefly on L., with vomiting for 16 yrs Required codeine-morphine b.i.d. Paranoid psychosis. Weight loss of 35 lbs.	None.	5/39	C3*	R.	C7	None.	Brief incomplete level to C7. Failure.
4. Kenneth W. MGH U-190636 Dr. W. J. Mixter	45	Severe lancinating pains in legs of 12 yrs. duration.	None.	5/41	T2-T3*	Bilat.	T8	None.	Complete relief at 7 mos.
5. Eleanor D. MGH U-434711 Dr. J. J. Michelsen	40	Congenital lues with severe L. abdominal crises for 5 yrs. Pantapon and dilaudid 2-4 i.d.	None.	1/44	T1	R.	T4	None.	Complete relief at 4 yrs., pt. working and leading normal life.
6. Fred S. MGH U-612762	59	Lancinating tabetic pains for 22 yrs., severe in legs and R. arm. Addicted to barbiturates and morphine.	None.	3/48	C2*	L.	C4	Temporary compression neuropathy of R. peroneal nerve due to position at operation.	Complete relief for 1 mo., then some throbbing sensation not described as pain, and analgesia found incomplete. At 4½ yrs. moderate residual pain not requiring opiates.
7. Donald B. MGH U-526114	49	Abdominal crises for 18 mos. with almost continuous attacks last 10 wks. Pain most severe on R Nausea and vomiting causing severe malnutrition. Atonic tabetic bladder.	None.	11/48	T1*	L.	T3	None.	At 5½ yrs. free of all complaints on analgesic side. Pain on opposite side too mild to require medication. On 72-hr. weekly work schedule, has gained 50 lbs.

*Testing of sensory level attempted at time of operation, in a small proportion of cases this could not be satisfactorily carried out.

placed on record eight further satisfactory cases. One patient continued to have short periods of vomiting without pain. These authors conclude that bilateral high thoracic cordotomy with a level of analgesia reaching to the nipples "offers practically certain abolition of the pain and vomiting after one operation."

The results of the seven operations performed at the Massachusetts General Hospital are summarized in Table XXXIII. There was a single failure and one patient was incompletely relieved, both because of imperfect operative technique. The other five had completely satisfactory results. In three of these section of the tract on one side was sufficient to do away with severe unilateral pain, evidence that previously published statements claiming that cordotomy must always be performed bilaterally in this condition are erroneous. In Patient 6 unilateral high cervical section was undertaken for relief of pain on the worse side, with the intention of performing a second stage procedure in the upper thoracic region for residual pain in the other leg. This plan of attack was unavoidable because of the need for high transection on the left side, where the lightning pains involved the arm as well as the leg, and because of the patient's distinctly poor condition. At follow-up examination seven months later, analgesia on the right was complete up to C5 except for the foot, and his crises of pain were so much reduced that he no longer required narcotics or further surgical intervention. This relief persists at four-and-a-half years postoperatively. He now writes, "Empirins quickly drive away mild attacks in my right arm or right leg . . . . two or three times a year I am awakened from sound slumber by a severe attack in my left calf." (The left side is not analgesic.) The marked reduction in pain in the nonanalgesic side, coupled with nearly complete relief on the other side, after unilateral cordotomy in Patients 6 and 7 is of particular interest to us. It adds evidence for the frequent ipsilateral conduction of some pain impulses and has led us to observe carefully the effect of the first cordotomy before proceeding to the other side. This was a particularly fortunate result in these two patients because each had annoying vesical symptoms which were not distinctly worsened by the first cordotomy, but might well have been by another one on the other side. In fact, Fred S. found after his cordotomy that he was able to feel urine passing through his urethra although this sensation had been absent preoperatively.

It is remarkable that the severe vomiting which often accompanies gastric crises is usually relieved as well as the accompanying pain. This was also observed by Hyndman and Van Epps (1939). These observations are at complete variance with the ideas expressed by Oldberg (1932), who

high interruption of the anterolateral pain tracts, that complications are rarely serious, and that a unilateral cordotomy should be recommended as soon as a patient begins to require heavy narcotic dosage for relief of tabetic pain.

D. HERPETIC PAIN

Chronic pain persisting after the lesions of herpes zoster have healed in elderly individuals may be a cause of profound and lasting distress. The sense of burning and cutaneous hypersensitivity which spreads over the affected dermatomes may be unbearable and last for years. These patients, because of their age and the complications that go with it, are often poor operative risks. In addition, their all too frequent psychotic states, a compound of cerebral arteriosclerosis, prolonged suffering, narcotic addiction, malnutrition, and avitaminosis, may make evaluation of the operative result a difficult task.

Neurosurgery should never be considered until all other methods of therapy have been tried. Injections of sodium cacodylate have been advocated by Peet (personal communication, 1943) and of neoarsphenamine by Gage (1949). Browder and de Veer (1949) have recently recommended wide excision and grafting of the skin and subcutaneous tissue. The results in four cases followed over one to two-year periods have been fairly promising with satisfactory relief in two, moderative improvement in the third, and little benefit in the fourth. We have had experience with only three cases. Here the skin and subcutaneous tissue involved by the herpetic scars were widely resected by Dr. Bradford Cannon without lasting benefit.

The futility of severing sensory roots for postherpetic pain has already been mentioned in Chapter XVI, wherein results of section of the retrogasserian root are shown to be rarely successful. Resection of posterior spinal roots has been attempted four times at the Massachusetts General Hospital, with one long-term success, one failure, one uncertain late result and one death from postoperative pneumonia. Foerster (1927A, p. 261) cites a patient in whom "lasting complete success" followed division of both anterior and posterior roots at T4 and T5, and mentions another good result obtained by Horsley following division only of the first sacral posterior root. Sympathectomy, which seems a totally illogical procedure, has also been tried and has failed.

In Kahn and Peet's (1948) recent description of spinothalamic tractotomy there are reports of six cases submitted to this operation. None was entirely successful. The level in one was only two segments above the painful zones [illegible] while in another the level fell. In two other [illegible] s well above the cutaneous lesions. In a 76-year-old man, whose case they described in detail, pain of sacral dis-

stated:* "There are certain things one must not expect this operation [cordotomy] to do. One of them is to relieve the vomiting which is so often associated with gastric crises of tabes dorsalis. This vomiting is vagal in character and so, of course, would not be affected by a spinal cord operation."

In view of the common impairment of neurogenic control of micturition, which is a characteristic of tabes dorsalis, it is surprising that cordotomy has not caused serious vesical disturbances in the great majority of patients. None of our patients complained of serious difficulty on this score at the time of their discharge; in fact, in Patient 7 an actual improvement was noted in the cystometrograms after operation. In Kahn and Barney's (1937) more extensive series, somewhat less than half complained of some continued difficulty, mostly in the nature of incontinence. Hyndman and Jarvis (1940) reported no disturbances of more than two weeks' duration.

It is fortunate that damage to the ventral (indirect) spinocerebellar tract does not increase ataxia, in view of the fact that damage to the posterior column fibres is so frequently a part of the tabetic syndrome. While we observed no complicating injuries to the pyramidal tract from incision anterior to the dentate ligament, an alarming incident occurred during operation in Patient 2. This woman stopped breathing briefly as the dura was opened and blood welled out from the upper part of the opening in the arachnoid. This and the fact that she developed a brief postoperative hemiparesis with partial aphasia led us to conclude that she had suffered a spontaneous cerebral haemorrhage, rather than injury to the spinal portion of the pyramidal tract from the incision. Fortunately, she made a good recovery and was thoroughly satisfied with the operation.

In contrast to these optimistic reports are the poor results recorded by Bagdasar (1937) in 10 tabetics in both gastric crises and lightning pains in the limbs; by Petit-Dutaillis (1937) in two cases and by Sicard and Robineau (1925) in two cases. None of these authors mentions the objective sensory examination after the cordotomy, so that we are unable to assess the technical adequacy of their operations. Banzet (1927) points out that in his four cases relief was obtained in only one, but that the pain was referred to non-analgesic areas in the other three.

Stebbing (1929) had the disappointing experience of seeing recurrence at 14 months, four years, and four years respectively in three of his five patients.

Evaluating these data, we may say in conclusion that there is ample evidence that *pain and vomiting are both likely to be terminated by effective*

---

*Oldberg, E.: Chordotomy. *S. Clin N. Amer*, 12:1315-1322, 1932, courtesy of W. B. Saunders Co., Philadelphia.

TABLE XXXIV

ANTEROLATERAL CORDOTOMY FOR RELIEF OF POST-HERPETIC NEURALGIA (4 CASES)

Patient	*Age*	*Description of Pain*	*Date*	*Level of Cordotomy*	*Side*	*Sensory Level*	*Complications*	*Result*
1. Minnie J. MGH U-273807 Dr. J. J. Michelsen	78	Neuralgia T9-T11 for 2½ yrs.	1/43	T2	R.	T6	None.	Excellent to death from intercurrent disease at 11 mos.
2. John F. MGH U-428956 Dr. J. J. Michelsen	67	Neuralgia C8 dermatome for 7 mos., requiring heavy narcotic medication. Threatened suicide. Previous trial of sodium cacodylate & injection of stellate ganglion without benefit.	1/41	C2	R.	C6	Right-sided weakness involving arm and leg, clearing after 1 mo.	Burning pain soon recurred with added complaints of occipital radiation. Longstanding psychoneurosis and depression made evaluation difficult. Followed 3 mos.
3. Simpson B. MGH U-381479	81	Neuralgia T3-T5 dermatomes for 2 yrs., with constant burning hyperaesthesia and intermittent shooting pains.	1/46	C2*	R.	C1	None.	Analgesic level persists at 5 yrs. & patient is leading normal life.
4. Vena O. MGH U-680841	31	Neuralgia of 3 yrs. duration from midthoracic spine to axilla and breast (L). Vomiting & weight loss to 86 lbs.	11/49	C1*	R.	Hypalgesia C3 Analgesia T1	Transitory right-sided weakness.	Former pain entirely gone. Good regain of weight & activity at 20 mos.

*Sensory level tested at operation.

We have recently had another excellent result in a fifth patient with post-herpetic neuralgia involving the eighth and ninth thoracic dermatomes, but insufficient time has passed to justify including her in this table.

tribution disappeared, but was replaced by a burning sensation which was sufficient to disturb sleep, despite an analgesic level to the nipple line. Peet (personal communication) stated that his operations on all these cases were done a good many years ago and the result with present-day technique should be better. Sjöqvist's (1949) report is, however, equally discouraging; five of his six cases had persistence of pain "in spite of hemianalgesia."

Our results, set forth in Table XXXIV, are more encouraging as three out of four patients have been relieved by anterolateral cordotomy. Patient 1 had complete relief of lower thoracic intercostal neuralgia until his death from intercurrent disease at 14 months. Patient 3 after five years was leading a normal life at 86 years of age. Patient 4 with a similar postherpetic neuralgia radiating from her upper back to axilla and breast, as well as severe malnutrition, maintained full analgesia to the first thoracic dermatome 20 months after cordotomy in the first cervical segment, and had gained 20 pounds in weight. Evaluation of the second patient is difficult on account of his many complaints and psychoneurotic background, yet after three months' observation the result must be set down as a failure. Complicating muscular weakness on the side of the cordotomy retarded the recovery in two, but soon cleared up. Considering the age and poor general condition of these patients, it is fortunate that no further complications were encountered.

It is apparent from this limited experience that properly executed spinothalamic tractotomy may or may not give satisfactory relief of postherpetic neuralgia, when the painful herpetic scars are situated below the mid-brachial outflow and the patient is not too seriously addicted to morphine. If one is correct in assuming that failures in patients with analgesia are due to lesions in the central nervous system, it appears possible that the virus of the zona localizes within the brain or cord more frequently in some regions of the world than in others, and that we have been fortunate on that score. When the upper cervical dermatomes are involved we do not recommend attempting to interrupt the spinothalamic tract in the highest cervical segments or medulla, because the operative risk appears to be too great in this group of elderly individuals and the chances of obtaining permanent analgesia in the upper cervical dermatomes are distinctly poor. For these difficult cases frontal leucotomy or one of its newer modifications appears to be the only solution. The following case history will serve to illustrate the desperate situation which may arise in an elderly arteriosclerotic individual with unendurable neuralgia following herpes zoster:

William L., MGH U-635061PH, 78: This retired manufacturer had long been under the care of Dr. E. P. Joslin for mild diabetes. In April, 1948, he suffered a severe attack of herpes zoster, which left a band of scarring and

CHAPTER XVIII

PAIN FROM INVOLVEMENT OF SOMATIC NERVES IN THE NECK, THORAX, ABDOMEN, PELVIS, AND EXTREMITIES

In contrast to sensation arising from the viscera proper, pain from the parietal pleura and peritoneum, or from malignant invasion of the intercostal nerves, brachial and lumbosacral plexuses cannot be relieved by sympathectomy. Afferent painful impulses from these sources pass through the spinal nerves and plexuses to enter the posterior roots and then cross in the anterior commissure to ascend in the contralateral spinothalamic tract. In order to secure an effective and lasting interruption the surgeon must therefore resort to posterior rhizotomy or spinothalamic tractotomy.

Methods of dealing with pain arising from thoracic and abdominal scars have been included in Chapter XIII. The variety of pain now to be discussed is seen primarily in the victims of advanced malignant disease. It is rare for pain to be a troublesome feature in its early stages when the tumour is confined to the breast, prostate, or gastrointestinal tract, but it often becomes a major problem in the care of patients during the terminal stages when the growth has invaded the thoracic or abdominal wall, periosteum, or the lumbosacral and brachial plexuses.

The patients to be discussed have mostly been seen in consultation in the tumour clinic, after every other known palliative method such as treatment by radiation, castration, or hormone therapy has been exhausted prior to transfer to the neurosurgical service.

The risks of laminectomy with posterior root section or anterolateral cordotomy may be considerable, because many of these sufferers are cachectic and may develop unexpected fatal complications after operation such as massive haemorrhage from erosion of major blood vessels, convulsions or coma from intracranial metastases, intestinal obstruction, or uraemia from ureteral occlusion. Nevertheless it has been the policy on the surgical services of the Massachusetts General Hospital to offer sensory denervation to these unfortunate individuals when they first begin to require morphine and to urge it strongly for all whose survival is likely to exceed the brief period before addiction becomes established.

hypersensitivity across his left upper back, axilla, and along the fourth rib in front. This had been a cause of constant and excruciating pain. When he entered the hospital it was evident that the patient had reached the end of his powers of endurance. In view of the fact that he had advanced generalized arteriosclerosis, mild decompensation, and electrocardiographic evidence of right bundle branch block and coronary disease, a high cordotomy could not be considered. As his period of survival seemed limited, we attempted to give him relief from pain by narcotic medication. Methadon (Amidon) supplemented by Demerol, Pantopon, or morphine at three-hourly intervals failed to give him any apparent relief. After unsuccessful trials with local procaine infiltration and freezing with ethyl chloride, a final consultation was requested with Drs. Joslin, Gilbert Horrax and Stanley Cobb. Despite the obvious risk, we were forced to accede to the patient's request and resort to radical surgery.

10/14/48: Bilateral frontal leucotomy. Operation was performed under local anaesthesia with the patient sitting up in a dental chair. The leucotomy knife was introduced laterally through burr holes in the coronal suture, according to the technique of Freeman and Watts. After making limited transections of both lower quadrants the patient still insisted that his suffering was unchanged. As the knife was then drawn gradually across the left upper quadrant he ceased speaking of his pain and became slightly euphoric. The incisions were then closed and the patient returned to his bed. During this period there had been no change in the pulse or blood pressure. When seen two hours later he was sitting up in bed talking with his nurse and asking to get up. When the nurse was told not to let him up till the morning the patient remarked facetiously, "That's right, sock him in the jaw." At this time he denied any pain whatever. A half-hour later, while talking with his nurse, he died almost instantly. Postmortem examination revealed a rupture of the left ventricle; haemopericardium and cardiac tamponade, recent myocardial infarction and coronary thrombosis with mural thrombus; severe generalized arteriosclerosis and chronic vascular nephritis. The areas of frontal white matter which had been cut across are shown in Figure 82.

In conclusion we recommend anterolateral cordotomy for relief of persistently severe post-herpetic pain, when the eruption has occurred below the level of the upper cervical dermatomes. There is no other solution except for some form of leucotomy, as other surgical procedures nearly always fail.

When pain is felt high in the neck recourse may be had to mesencephalic tractotomy, but this is fraught with considerable risk in individuals with advanced malignant disease and is followed all too frequently by disagreeable persistent paraesthesiae. Trial and error have convinced us that spinothalamic tractotomy, whether carried out at the second cervical segment or even in the medulla, cannot be counted on to give lasting analgesia in the neck or even throughout the distribution of the brachial plexus. Patient 16, with

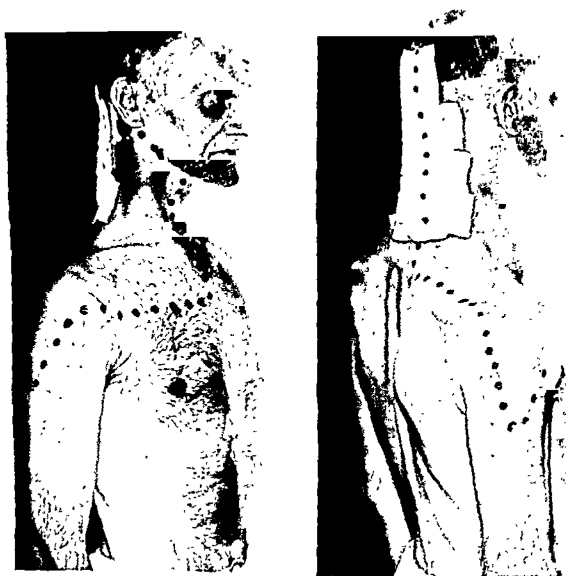


Fig 123. Carcinoma of right submaxillary gland and cervical nodes: Area of anaesthesia produced by section of posterior roots down through fifth cervical.

In most instances sensory loss will extend a short distance above the angle of the jaw over the attachment of the masseter muscle.

There was initial complete relief of this patient's (Manuel F., MGH U-708228) pain and he remained sufficiently improved at four months after operation so that he felt no further surgery was necessary. This case is too recent to be included in Table XXXV.

A. EXPERIENCE WITH PAIN IN VARIOUS LOCATIONS

To illustrate the methods of dealing with these difficult cases and to evaluate their effectiveness, we have broken down case reports of 155 patients according to the focus of origin of their pain, tabulating the over-all results, and giving illustrative cases in greater detail. These cases represent consecutive patients operated upon during a 10-year period from 1938 through 1948, with the exception of the year 1943, when both of us were away on war service.

1. Cervical Tumours

Pain from malignant invasion of the neck is one of the most perplexing problems which the neurosurgeon is called upon to treat, especially when the primary lesion is situated in the oropharynx. Our difficulties in controlling pain radiating to the face, mouth, and ear, as well as the neck, are discussed in Chapter XVI. Involvement of the brachial plexus, when carcinoma of the breast or apex of the lung invades the supraclavicular nodes, is taken up in the two following sections. Included here are methods of desensitizing tumours which have invaded the cervical plexus and given rise to pain radiating to the occiput, neck, and shoulder.

When the throat and neck are involved pain is often not the only distressing factor, as the patient may be kept in a state of mental torture by fear of imminent death from haemorrhage, choking, or inability to swallow. Some form of frontal leucotomy is the only solution for these conditions, as illustrated by Patients 11, 13, and 17 in Table XXXV. The results were gratifying in the last two, while Patient 11 proved to be one of the rare failures we have had with leucotomy in the treatment of malignant disease with brief survival. The history of Roy P. is given on page 305 and the details of the other successful case are recorded below:

Wilbur L., MGH U-233175, a 55-year-old man with fibrosarcoma at the base of the neck, had had many operations on the surgical service, followed by recurrence. The tumour, which was compressing his trachea and oesophagus, made swallowing difficult and the patient was in constant dread of choking. He had derived little benefit from posterior rhizotomy, as pain recurred both above and below the zone of anaesthesia. After bilateral cutting of the lower quadrants of the frontal lobes he was relieved of pain and apprehension for a month. When the pain recurred the operation was extended to a complete leucotomy on both sides. He then became somewhat childish and disoriented until his death nine days later of tracheal obstruction. Although this unfortunate individual survived for only a brief period after the second and more complete leucotomy, his suffering and terror of imminent strangulation had been so pitiful that the operation may be regarded as a happy solution.

9. Michael D MGH U-343179	67	Recurrent carcinoma tongue with L cervical metastasis.	L. neck, occiput, and mandible	10/45	C2-C5 posterior rhizotomy.	L.		Relief except in third division of trigeminus, to death in 6 mos.
10 Mary D. MGH U-82795	46	? Syringomyelia cervical cord.	R. shoulder, neck, and posterior quadrant of scalp.	5/47	C1-C4 posterior rhizotomy.	R.		Relief of pain persisting at follow-up 5½ yrs. later.
11. Charles B. MGH U-586867	35	Carcinoma metastatic to neck.	L neck.	11/47	C2-C5 posterior rhizotomy.	L.	Anaesthesia posterior quadrant scalp to 2nd rib, acromion process and superior border scapula.	Recurrence of pain in undenervated areas within 2 wks. This not relieved by bilateral frontal leucotomy.
12. Louis D. MGH U-517722 Dr. H. T. Ballantine	67	Recurrent carcinoma larynx with cervical metastasis.	R neck and throat.	1/48	C2-C5 posterior rhizotomy.	R.	Same as in Case 11.	Satisfactory relief for 1 mo., but severe pain recurred. Died within year.
13. Wilbur L. MGH U-233175	53	Fibrosarcoma R. clavicle and neck.	R. neck, occiput, shoulder, and arm.	2/48	C2-C5 posterior rhizotomy.	R.	Same as in Case 11.	Recurrence of pain soon in areas rostal and caudal to anaesthetic zones. Leucotomy done.
14. Lillian G. MGH U-509574	45	Carcinoma metastatic to neck.	L. neck and occiput.	11/49	C2-C4 posterior rhizotomy.	L.		Severe pain soon appeared in L. arm and R. side; death in 6 wks.
B Anterolateral Cordotomy								
15. Christine F. MGH U-355507	54	Carcinoma of breast removed 6 yrs. earlier; metastasis to neck 2 yrs. previously.	R. neck and arm.	5/42	Posterior rhizotomy C1-3. Cordotomy C2.	R. L.		Relief of pain complete until death 9 mos. later.
16. Michael K. MGH U-407259 Dr. J. J. Michelsen	47	Epidermoid carcinoma R. neck.	R. neck, shoulder, and arm.	6/43	C2 cordotomy.	L.	C7 analgesia.	Haemorrhage from oesophagus or trachea. Inadequate relief; died of his disease in 3 wks.
C. Frontal Leucotomy								
11. Charles B. — See above.								
13. Wilbur L. — See above and case history on p. 570.								
17. Roy P. MGH U-712153	26	Melanotic sarcoma at base of neck with invasion of brachial plexus. See case history on p. 305.	R. neck, shoulder, and arm.	12/50	Unilateral frontal leucotomy.	L.		Complete freedom from pain with mild mental changes. Choked to death at 5 wks. without preliminary concern.

TABLE XXXV

TUMOURS OF NECK (17 CASES)

Patient	*Age*	*Tumour - Type and Location*	*Pain Reference*	*Date*	*Operation*	*Side*	*Sensory Findings*	*Result*
A. *Posterior Rhizotomy*								
1. Emma T. MGH U-356836 Dr. J. S. Hodgson	52	Primary carcinoma. Previous tracheotomy.	L. neck with shoulder radiation.	10/36	C2-C5 posterior rhizotomy.	L.	Anaesthesia occiput to shoulder.	Satisfactory relief for about 6 mos., but required heavy morphine medication prior to death at 10 mos.
2. Irvin G. MGH U-357856 Dr. J. S. Hodgson	55	Carcinoma at right angle of mandible.	Deep in R. throat, ear, eye, and gums.	12/36	Crushing posterior roots C1-4.	R.		Pain in R. face till death 5½ mos. later.
3. Frank M. MGH U-16355	61	Primary epidermoid carcinoma with compression of trachea.	L. ear, neck, and shoulder. Previous section of superficial cervical plexus was ineffective.	8/37	C2-C5 posterior rhizotomy.	L.	Anaesthesia occiput to shoulder.	Relief for 5 mos; death at 6 mos.
4. William H. MGH U-113182 Dr. J. S Hodgson	62	Carcinoma tongue with metastases below L. jaw.	L. occiput, ear, and neck.	3/38	C2-C5 posterior rhizotomy.	L.	Anaesthesia occiput to shoulder.	Relieved of neck pain with moderate residual in third division of trigeminus. Died in 4 mos.
5. Frank S. MGH U-69596 Dr. W. J. Mixter	71	Carcinoma L. submaxillary area.	L. neck.	8/38	C2-C5 posterior rhizotomy.	L.	Anaesthesia L. posterior quadrant scalp, neck, and upper third lateral arm.	Relief of left-sided pain; some pain on R. before death in 5 mos.
6. Martin M. MGH U-158805 Dr. J. J. Michelsen	64	Recurrent carcinoma tongue with cervical metastasis.	L. ear, neck, and shoulder.	11/38	C1-C4 posterior rhizotomy.	L.		Some discomfort in anaesthetic area behind ear and over shoulder, but wife said operation reduced pain greatly.
7. John N. MGH U-173901 Dr. J. J. Michelsen	65	Epidermoid carcinoma tongue, metastatic to R. parotid and submental regions.	R. head and neck.	3/39	C2-C5 posterior rhizotomy.	R.		By 2 wks. after operation severe pain in throat.
8. Clarence B. MGH U-23982 Dr. J. J. Michelsen	69	Recurrent carcinoma lip with metastasis to R. side of neck.	R. neck.	3/40	C1-C4 posterior rhizotomy.	R.		Postoperative pneumonia Complete relief, but operative death on 13th day. General carcinomatosis, diabetes, and coronary disease.

roots in Patient 4 and section of the tract in the medulla in Patient 8. An operative death in a woman with advanced carcinomatosis (Patient 6) followed a probable pulmonary embolus.

Patients in the terminal stages of mammary carcinoma are subject to such widespread metastases that unilateral cordotomy, even if it produces a high thoracic level of analgesia, is likely to fail. Most frequently new spinal or bony metastases cause pain to develop on the opposite side, or supraclavicular nodes compressing the brachial plexus may produce a higher level of ipsilateral pain. These difficulties are illustrated by the following case history:

Patient 10, Lucille R., MGH U-584530, 54. A vigorous middle-aged woman had had a radical left mastectomy two and a half years prior to admission. She later developed metastases so painful that they forced her to resort to large doses of Demerol and morphine. A year before, treatment with testosterone and stilbestrol by Dr. Ward Gregg had brought about an apparent disappearance of the bony lesions. In August, 1948, osteoblastic metastases reappeared in her fifth, sixth, and seventh thoracic vertebrae, another in the left side of her pelvis, and a soft tissue mass over the fifth rib on the right. She was bedridden and required codeine and Pantopon 4 i.d. for relief of pain, which was extremely severe on any movement of the left hip.

On 9/27/48, after the relatively minor risks of unilateral cordotomy as compared with the bilateral procedure had been explained to the patient, the right spinothalamic tract was cut to a depth of 5 mm. at the second thoracic segment. Anaesthesia, consisting of procaine infiltration with supplementary Pentothal and nitrous oxide, permitted awakening the patient for testing. On the first trial the level of analgesia was found to reach no higher than the iliac crest. Two further sections, extending nearly to the median sulcus, were necessary before the level reached the seventh rib.

Except for transitory weakness of the right leg, her postoperative course was uneventful. She began to void without residual when the Foley catheter was removed at the end of a week. The T7 level was maintained, and she was able to sit up in a chair free of the old severe pain in her left hip. She remained in the hospital for over a month, as Dr. Gregg gave her a further course of testosterone and stilbestrol. At discharge she declared that she had only slight discomfort in her left upper chest and that the right-sided pain was quite bearable. The slight residual weakness in her right leg gave her no inconvenience. She estimated the over-all result as about a 50 per cent improvement. This alleviation, however, was of short duration. She soon reported from her home in New York that pain was unbearably severe on her right side and in her left upper chest as well. At our suggestion she consulted Dr. John E. Scarff, who found metastases developing in almost every bone of her body. Unilateral frontal leucotomy was therefore carried out at the New York Neurological Institute, from which, Dr. Scarff wrote, she obtained a great measure of relief.

pain involving the right side of his neck, shoulder, and arm, illustrates the futility of this procedure. This man soon after operation complained again of his pain, which was not interrupted by analgesia to the seventh cervical segment, and he died within three weeks of massive haemorrhage from his growth.

Chances of success will be greater if the ipsilateral posterior upper cervical roots are divided in addition to high transection of the spinothalamic tract. This is exemplified by Patient 15, who was relieved of her pain in the neck and arm during the remaining nine months of her life. We may justifiably be criticized for having used this combined procedure so seldom, and intend to utilize it more frequently in the future.

When the pain of cervical tumours is confined to the cervical plexus with complaints limited to the neck and occiput, division of the upper three or four posterior roots is a relatively simple procedure that frequently yields worth-while results. The type of growth that is prone to produce unbearable pain in the cervical plexus and the area of anaesthesia that follows division of the posterior roots down through the fifth are illustrated in Figure 123. Table XXXV shows that this procedure gave satisfactory relief in the neck over the relatively brief periods of survival in six individuals. Three of these (Patients 2, 4, and 9) still complained of some discomfort in the trigeminal area. Patient 5 developed pain in the opposite side of the neck, but they all remained grateful for what had been accomplished. Patients 1, 12, and 14, after a few weeks to six months of relief, suffered severe recurrences. Patients 7, 11, and 13 were early failures and 8 was an operative death. In contrast, Patient 10, whose pain was caused by syringomyelia rather than malignant disease, continues free of pain at five and a half years.

2. Breast Tumours

Pain from carcinoma of the breast is rarely experienced as long as the disease remains localized, but is a common occurrence when the growth invades the brachial plexus and chest wall, or metastasizes to the spine, pelvis, or long bones. Our experience is based on 17 cases, nine treated by anterolateral cordotomy, five by section of posterior roots, one by a combination of the two procedures, and three by frontal leucotomy (one of whom had had a previous unsuccessful cordotomy). We are far from proud of the results in Table XXXVI.

In the 10 cordotomized patients completely satisfactory results were achieved in only three. In three others some pain, subsequently developing on the opposite side, marred an otherwise satisfactory outcome. Frank failures occurred in three from difficulty in achieving a sufficiently high cervical level of analgesia, even with added section of ipsilateral posterior cervical

Lucille R. MGH U-584550	51	Recurrent carcinoma with metastases to ribs, spine, and pelvis.	L. leg and abdomen. Bed-ridden from pain on any movement.	9/48	T2*	R	T7	Slight residual weakness of R. leg.	Relief of left-sided pain, but was developing pain in R. side on discharge at 5 weeks. This necessitated unilateral leucotomy at another hospital, which gave "a great measure of relief." Died at 26 months.
B. *Posterior Rhizotomy*									
11. Isabel W. MGH U-22823	49	Carcinoma breast with extension to supraclavicular nodes and brachial plexus.	R arm with partial paralysis.	9/37	C5-T1	R.		None.	Pain greatly improved for 16 months, then severe in R. leg with new mestastases.
12. Mary B. MGH U-167348	40	Carcinoma breast with recurrent involvement brachial plexus.	R. arm with oedema and paralysis.	12/38	C4-T1	R.		None.	Failure.
				1/39	C2-C3 and T2	R.		None.	Continued pain in hand and forearm to death at 2½ months.
13. Catherine C. MGH U-36925	52	Carcinoma breast.	R. arm and axilla with paralysis.	12/38	C2-T5	R.		None.	Considerable relief but pain in anaesthetic hand before death in 3 months.
14. Nettie B. MGH U-177483	65	Carcinoma breast with recurrent involvement brachial plexus.	L arm with oedema and partial paralysis	2/39	C3-T2	L.		None.	Complained of moderate discomfort at 7 months, but L.M.D. wrote she was free of pain at 19 months. Then severe recurrence prior to death in 1941.
4. Catherine D. MGH U-48762	68	(See under A. in this table.)	Pain in arm continued despite previous cordotomy of 9/39.	9/39	C3-C6	R		None.	Failure. Patient addicted to morphine and final status uncertain. Died at 1 year.
				10/39	C7-T3	R.		None.	
				11/39	Brachial plexus resection.	R		None.	
15. Miriam K. MGH U-302702 Dr. W. J. Mixter	43	Recurrent carcinoma with supraclavicular invasion of brachial plexus	L. shoulder and arm with paralysis.	5/41	C5-T2	L.		None.	Slight residual pain above clavicle with complete relief in arm at discharge, but pain recurred and husband felt operation was useless. Died at 3 months.
C. *Frontal Leucotomy*									

Patient 10 above and Patients 14 (Myrtis B.) and 22 (Helen R.) of Table XII (p. 301), which are discussed below in the text.

*Sensory level verified at operation.

TABLE XXXVI

TUMOURS OF BREAST (17 CASES)

Patient	*Age*	*Tumour - Type and Location*	*Pain Reference*	*Date*	*Level of Operation*	*Side*	*Sensory Level*	*Complications*	*Results*
A. *Spinothalamic Tractotomy*									
1. Mary M. MGH U-233172 Dr. J. S. Hodgson	55	Recurrent carcinoma in axillary scar.	L shoulder and arm.	7/36	C3*	R.	C5	None.	Failure from inadequate level. Continued pain in dermatomes C3 and C4 at 4 months
2. Mary K. MGH U-204715	46	Carcinoma breast with metastases to lumbar spine and sacrum.	L buttock and thigh, with swollen leg	8/39	T3*	R.	T9	None	Relief of L leg pain, but some residual low backache with mild radiation to R leg at discharge No follow-up
3 Emma W. MGH U-129603 Dr. J. S. Hodgson	41	Carcinoma breast with metastasis L3 vertebra and pathological fracture	Low back with radiation to paralyzed R. leg.	8/13/39	C6-C7	Bilat.	Incomplete.	None.	Failure. Inadequate level.
				8/21/39	C6-C7*	Bilat.	T7	None.	Complete relief at discharge. Died 1940.
4. Catherine D. MGH U-48762	68	Recurrent carcinoma breast with extension to upper ribs and brachial plexus.	R. arm, with partial paralysis and oedema.	9/39	C5 and rhizotomy on R. C3-C6*	L.	Incomplete above T2	None.	Failure from inadequate level at 1 year. (See under B in this table.)
5. Eva H. MGH U-314695	47	Carcinoma breast with metastases to C7 and several lower vertebrae with compression fractures.	R. chest and abdomen, beginning paraplegia	8/41	C3	L.	Complete T5, hypalgesia C5	None.	Complete relief on R. with mild residual on L., *which did not require* surgery, to death at 4½ months.
6. Anna B. MGH U-476249	51	Recurrent carcinoma breast with bony metastases in ribs, vertebrae, pelvis, and femur. Poor operative risk.	Pain in back and legs so severe that operation was undertaken despite obvious risk.	1/45	T2-T3	Bilat.	Uncertain.	Probable pulmonary embolus.	Operative death on 6th day.
7. Bessie C. MGH U-481528 Dr W. J. Mixter	66	Recurrent carcinoma with pelvic, rib, and pulmonary metastases.	L L Q. and back.	4/45	T2	R.	T6	None.	Relief to death in 2 months.
8. Mary C. MGH U-412312	63	Recurrent carcinoma breast with supraclavicular and pulmonary metastases.	L shoulder and arm.	11/45	Bulbar	R.	C1	None.	Successful at first, but sensory level fell with recurrent pain in arm. Death at 7 months.
Ruth L. MGH U-556768	50	Recurrent carcinoma with involvement of brachial plexus.	R. chest, shoulder, and arm.	4/47	C2*	L	C6	None.	*Relief for 1 year, then* new pain with cervical metastases. Died at 21 months

spinal roots divided from C4 to C7. There were no serious complications, but the level of permanent analgesia only reached T2, leaving a gap in the denervated zone over the eighth cervical and first thoracic dermatomes.

The pain was still severe and she became addicted to morphine. Accordingly on 10/20/39 the laminectomy was extended and the posterior roots from C8 to T3 were severed. The arm and axilla were then thoroughly devoid of sensation, but her complaints were in no wise reduced. A month later the brachial plexus was resected, and microscopic examination showed direct invasion by cancer cells (Fig. 124). At the time of discharge she still complained of lancinating pains throughout the anaesthetic arm, the cause for which we were at a loss to explain.

This case is cited to show that, despite present-day anatomical knowledg of sensory pathways, there are certain types of pain which cannot be relieve by the available methods of sensory denervation. For this group, fortunate! a small one, and for the greater number of patients with widespread meta tases in the ribs, sternum, or upper thoracic vertebrae, frontal leucotomy perforce the operation of choice. Our experience has shown that a unila eral transection, provided the frontal white matter is completely cut acros is usually capable of giving effective relief for a period up to six months an without serious psychological deterioration. In Patient 10 considerab benefit lasted well over this period. Another patient (Myrtis B., in Tab XII, p. 301), in whom there was unbearable pain from a metastasis in a upper thoracic vertebra, had recurrent complaints after eight months ar was suffering severely at 16 months. She then developed a comple paraplegia and thereafter lived with relative freedom from pain during tl final months of her life. In our third patient, who survived only fo months, this limited procedure proved to be an ideal solution. This ca history is given in detail on page 304. After the unilateral leucotomy sl no longer complained of her former pain and required no medication exce for an occasional aspirin tablet. She remained relatively free of discomfo and met death with equanimity four months later.

3. Tumours of the Lung

Tumours of the lung are most likely to cause unbearable pain when the involve the superior pulmonary sulcus (Pancoast syndrome), or invade tl parietal pleura and intercostal nerves, or metastasize to the vertebrae. I our series of 12 cases, summarized in Table XXXVII, there were seven of tl former. This group with malignant invasion at the apex of the lung, as d scribed by Pancoast, characteristically suffer paralysis of the brachial plexu phrenic and recurrent laryngeal nerves, and the cervical sympathetic trui (Fig. 125). So many major nerve trunks are involved that severe pain this high level is particularly difficult to relieve High cervical cordoton

Six patients were treated by laminectomy and division of posterior spinal roots for pain in the shoulder and arm which followed invasion of the brachial plexus, generally with a pre-existent paresis and oedema of the painful extremity. Pain in the arm was effectively relieved for 16 months in Patient 11, but is known to have recurred after 19 months in Patient 14. Duration of relief was all too brief in Patient 15, and not even initial success was achieved in Patients 4, 12, and 13, even though the rhizotomies in two extended over nine spinal segments. One of these is of particular interest:

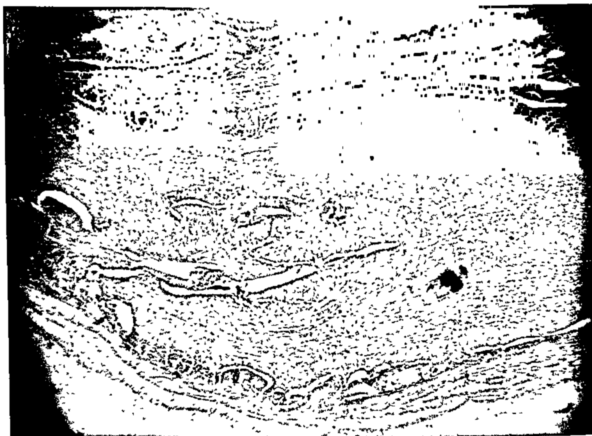


Fig 124. Metastatic cancer of breast with intractable pain in paralyzed arm
Photomicrograph showing carcinoma cells invading a trunk of the brachial plexus (Patient 4, Table XXXVI)

Patient 4, Catherine D, MGH U-48762, 68. Radical mastectomy performed in another hospital five years before had been followed by an ulcerative recurrence in the upper thoracic wall, with painful paralysis and swelling of the right arm, which was practically useless Heavy radiation had been tried without effect.

In September, 1939, left anterolateral cordotomy was performed at C3 under local anaesthesia. The patient was not very cooperative in testing, but analgesia seemed to be present up to the lower cervical segments. General anaesthesia was then induced with Pentothal and the right posterior

3. Michael R. MGH U-48287	36	Superior pulmonary sulcus tumour with rib metastases.	L. shoulder, arm, and chest.	6/15	C2	R. T2	None.	Relief of pain in chest but failure in arm. Died 1 month.
). Stanton B. MGH U-497833	59	Bronchogenic carcinoma with metastases to ribs, pelvis, and testicle.	R. chest, pelvis, and leg.	10/45	T2*	L. T1	Transitory paralysis of urination and poor healing of wound.	Relief right-sided pain with mild residual on L., to death in 4 months.

B. Frontal Leucotomy.

3 Patients, summarized in Chapter X (Tables X and XII) are discussed in text below.

*Sensory level verified at operation.

Table XXXVII

TUMOURS OF LUNG (12 CASES)

Patient	Age	Tumour - Type and Location	Pain Reference	Date	Level of Cordotomy	Side	Sensory Level	Complications	Result
A. *Spinothalamic Tractotomy*									
1. Peter P. MGH #351411	46	Superior pulmonary sulcus tumour.	R neck, upper chest, shoulder, and arm.	3/36	C4* and rhizotomy on R. C4-C7	L.	Anaesthesia C4-C7, analgesia below T2.	None.	Fair relief, with some pain felt in C8 and T1 dermatomes at 1 month with later severe recurrence. Died within 9 mos.
2. David L. MGH #352704	53	Superior pulmonary sulcus tumour.	L. shoulder and medial side of arm.	4/36	C4* and posterior root crushing on L., C7, C8.	R.	Anaesthesia C7-C8, analgesia to T1.	Transitory weakness R. arm and leg.	Satisfactory relief on analgesic side to death, 3 mos. Mild pain opposite side relieved by codeine.
3. George D. MGH U-255983 Dr. J. J. Michelsen	42	Colloid carcinoma upper lobe lung with metastases to neck and cervical spine.	L chest and arm with attacks of dysphagia.	4/41	C3*	R.	C7	None.	Relief at discharge. Readmitted in coma and died of respiratory failure at 5 weeks.
4. Frank H. MGH U-313824	40	Superior pulmonary sulcus tumour.	R. chest, shoulder, and arm.	9/41	C3*	L.	Analgesia to C5.	Fell and fractured skull on 4th postoperative day.	Satisfactory relief but died of fractured skull and intracranial injury on 4th day.
5. Myer B. MGH U-331216 Dr. W. J. Mixter	72	Bronchogenic carcinoma with superior pulmonary sulcus syndrome.	R. chest, shoulder, and arm.	2/42	C3	L.	C4	None.	Relief to death at 2 mos. New pain from spontaneous fracture opposite arm.
6. Frank G. MGH U-341788 Dr. J. J. Michelsen	69	Superior sulcus bronchogenic carcinoma, arteriosclerotic coronary disease and chronic nephritis.	L. chest, shoulder, and medial arm.	3/42	C2	R.	C5	L. pulmonary atelectasis and pneumothorax.	Complete relief but operative death on 3rd day.
7. Leonard C. MGH U-380230 Dr. J. J. Michelsen	52	Carcinoma L. lung with metastases to L2 vertebra, ribs, adrenals, etc.	R. chest, shoulder, low back, and L. leg	12/42	C2 T3	L. R.	Uncertain.	Compression superior vena cava and bilateral hydrothorax.	Relieved of pain but died of his disease on 12th day.

Michael R. MGH U-48287	38	Superior pulmonary sulcus tumour with rib metastases.	L. shoulder, arm, and chest.	0/45	C2	R.	T2	None.	Relief of pain in chest but failure in arm. Died 1 month.
Stanton B. MGH U-497833	59	Bronchogenic carcinoma with metastases to ribs, pelvis, and testicle.	R. chest, pelvis, and leg.	10/45	T2*	L.	T4	Transitory paralysis of urination and poor healing of wound.	Relief right-sided pain with mild residual on L., to death in 1 months.

B. Frontal Leucotomy.

3 Patients, summarized in Chapter X (Tables X and XII) are discussed in text below.

*Sensory level verified at operation.

with added division of ipsilateral posterior cervical roots gave only brief respite in Patient 1, but a satisfactory result over the brief period of observation in a second. The details of the latter are worth a brief summary:

Patient 2, David L., MGH U-352704, 53. In December of 1935 the patient developed a hacking unproductive cough with dyspnoea on exertion and night sweats. In February he began to complain of upper thoracic pain, which in March radiated down the inner side of his left arm to the ring and little fingers. These soon became numb, although there was no obvious



Fig. 125. Malignant tumour of right superior pulmonary sulcus causing severe pain in arm, shoulder, and neck

This photograph of Patient 1, Table XXXVII, shows the characteristic swelling in the supraclavicular fossa and right arm with evidence of venous congestion and Horner's sign. In addition this patient had a hoarse voice and elevated right diaphragm from compression of the vagus and phrenic nerves.

motor weakness. The arm was dry and distinctly warmer than the right. On admission in April he had a definite Horner's sign, but his voice was not hoarse and the diaphragm not paralyzed. X-rays showed a hazy dullness of the left apex with destruction of the posterior portion of the first and second ribs. Dr. Donald S. King thought that the primary lesion was a bronchogenic carcinoma and that the only surgical treatment indicated was for relief of his uncontrollable pain.

4/16/36: Right anterolateral cordotomy at C4 was carried out with the patient anaesthetized by regional infiltration of procaine and supplementary nitrous oxide. He was then allowed to awaken. The level of analgesia extended only to his iliac crest. The previous 5 mm. deep incision was then extended anteriorly nearly to the midline of the cord, whereupon the sensory level was found to reach the axilla. After a third, somewhat deeper incision pin-prick was no longer painful in the ulnar side of his hand. After this he was again put to sleep with nitrous oxide and the seventh and eighth posterior spinal roots were crushed on the left side between the blades of a mosquito snap. His convalescence was satisfactory except for some weakness of his right arm and leg, which was recovering well when he was discharged. At this time the sensory level reached the centre of his hand and he was almost completely free of pain, but follow-up letters sent this patient and his family have not been answered.

In our earlier attempts to obtain high levels of analgesia we were reluctant to place the cordotomy incision above the third cervical level. These fears have proven unfounded, as described in Chapter VIII. With the present-day technique of placing the incision just below the first cervical root a far higher incidence of durable analgesia in the arm can be attained.

All the other patients in whom a satisfactory high level of analgesia was reached by anterolateral cordotomy without added section of posterior roots were effectively relieved for brief periods of survival. Two of these unfortunately succumbed: Patient 4, an alcoholic who fell when he got out of bed, died of a fractured skull and intracranial injury; Patient 6 died of postoperative atelectasis and pneumothorax. A third, less serious complication consisted of a transitory right arm and leg weakness in Patient 2. Patient 8 failed to obtain relief of pain in his arm because of incomplete division of the anterolateral pain tract.

Of the two other cases of carcinoma of the lower portions of the lung and widespread metastases, Patient 7 died of his disease on the twelfth day after operation and Patient 9 had a good result following unilateral cordotomy, but mild residual discomfort on the other side. The latter had transitory retention of urine as well as poor healing of his incision.

We have also treated two other patients with malignant involvement of the apex of the lung or superior mediastinum by frontal leucotomy. These patients, in addition to pain extending high up into the neck, had difficulties

in swallowing and fear of haemorrhage or strangulation. They are summarized in Tables X (Patient 4) and XII (Patient 26) in Chapter X. Although relieved of their outward manifestations of pain and mental suffering, one died within a month and the other was observed for only three weeks.

4. Tumours of the Gastrointestinal Tract

Tumours of the lower digestive tract are rarely painful until they have invaded the retroperitoneal space. If the lesion is situated in the oesophagus and there is deep invasion of the cervical tissues, the pain is very difficult to relieve, and the mortality from bulbar tractotomy in cachectic patients is likely to be high. In our two cases, summarized in Table XXXVIII, one died on the operating table; the other, although relieved of her pain, expired a week later of exsanguinating haemorrhage from erosion of her jugular vein. If confronted by similar problems again, we would recommend frontal leucotomy.

In our single example of carcinoma of the stomach the painful metastasis developed in the pelvis and was easily relieved by bilateral section of the anterolateral pain tracts performed in two stages. More commonly there is direct invasion of the retroperitoneal space in the region of the coeliac axis. The pain will then be situated in the epigastrium, where relief can also be readily obtained by cordotomy.

Pain from nonmalignant disease of the liver, biliary tree, and pancreas can be relieved so frequently and with so little risk by thoracic sympathectomy and splanchnicectomy that in such cases this operation should be used in preference to cordotomy. This was not known in 1941. Patient 4, with persistent right upper quadrant and back pain after multiple operations for chronic gall bladder disease and pancreatitis, was therefore treated by anterolateral cordotomy. He remained free of pain for four years and then is reported to have died of deepening jaundice. It is of particular interest that a satisfactory result was obtained by unilateral section because, on the basis of animal experiments, Ranson and Clark (1947) and Davis, Hart, and Crain (1929) claimed that visceral pain always ascends on both sides of the spinal cord (see p. 263). This conclusion, insofar as we have tested it, is fortunately not usually true of man, despite Foerster's (1927A, p. 105) statement that unilateral cordotomy does not produce contralateral analgesia of the viscera.

Carcinoma of the lower intestinal tract, colon, and rectum usually spreads in the paravertebral lymphatics to invade the lumbosacral plexuses and thereby produces pain radiating to the pelvis and legs. Low pain of this sort is particularly favourable for interruption by spinothalamic tractotomy, but the operation usually has to be performed on both sides. Ex-

TABLE XXXVIII

TUMOURS OF GASTROINTESTINAL TRACT (29 CASES)

tient	*Age*	*Tumour - Type and Location*	*Pain Reference*	*Date*	*Level of Cordotomy*	*Side*	*Sensory Level*	*Complications*	*Result*
othalamic Tractotomy									
Oesophagus									
1. Blanche M MGH U-480674	42	Carcinoma oesophagus with cervical metastases.	R. occipital, cervical, brachial, and upper thoracic.	12/45	Bulbar*	L.	C4	Exsanguination from erosion of jugular vein.	Death from disease 1 week (non-operative).
2. John K. MGH U-542349	56	Carcinoma oesophagus with cervical and upper thoracic metastases.	R. shoulder and scapula.	1/47	Bulbar*	L.		Respiratory and cardiac failure.	Operative death on table.
B Stomach									
3. Ralph M. MGH U-422974	40	Pelvic mass which on biopsy suggested metastatic carcinoma of stomach.	R. back, groin, testicle, and leg.	11/44	T2*	L.	T7	Minor postoperative sepsis in incision.	Relief on R. 3 mos.
				1/45	T3*	R.	T10	Transitory retention urine, but voiding at discharge.	Relief bilaterally at discharge. Died 4 mos.
C. Gall Bladder									
4. James M MGH U-302678 Dr W. J Mixter	41	Post-cholecystectomy pain with chronic pancreatitis.	R.U.Q. and back, relieved by R. paravertebral procaine block.	7/41	T2*	L.	T5	None.	Relief of abdominal pain to death 4 yrs. later of obstructive jaundice.
D. Colon and Rectum									
5. William H. MGH U-6540	44	Recurrent colloid adenocarcinoma rectum with liver metastases.	R costal margin and lumbar region.	3/37	T3*	L.	Analgesia T12, hypalgesia T5	None.	Relief at discharge. Died within year.
6. Charles O. MGH U-10882	52	Recurrent carcinoma rectum with spread to lumbosacral plexus.	Perineum and R. thigh.	4/37	T2* T3*	L. R.	R. L1 L. None.	Transitory residual urine 600 cc. with lasting slight incontinence.	Satisfactory relief to death at 4 mos.
7. James Wo. MGH U-18291 Dr. W. J. Mixter	42	Recurrent carcinoma rectum with spread to lumbosacral plexus.	L. buttock with radiation down leg to ankle.	9/37	T2 T3	L. R.	**	Serious paralysis of bladder causing death from urinary infection in 10 weeks.	Effective relief of leg pain, then higher level pain from T6 vertebral metastasis. Died 10 weeks.
8. Walter D. MGH U-116426	50	Inoperable carcinoma rectum. Previous colostomy.	Both sides of lower abdomen and pelvis.	4/38	T2* T3*	L. R.	T10 T10	Previous paresis of bladder due to tumour infiltration.	Satisfactory relief of pain, family most grateful. Died 4 mos.

TABLE XXXVIII

TUMOURS OF GASTROINTESTINAL TRACT (29 CASES)—Continued

Patient	Age	Tumour - Type and Location	Pain Reference	Date	Level of Cordotomy	Side	Sensory Level	Complications	Result
9. Emma H. MGH U-140415 Dr. J. S. Hodgson	71	Recurrent carcinoma rectum with perineal and liver metastases.	Perineal pain. Intrathecal alcohol block without benefit.	7/38	T1° C8°	L. R.	T7 T7	Urinary retention with improvement at 3 weeks.	Relief at discharge, but family report partial recurrence before death in 1939.
10 James Wa. MGH U-11883 Dr. J. S. Hodgson	52	Recurrent carcinoma rectum in perineum.	Perineum.	7/38	T1° C8°	L. R.	T10 T8	Paresis R. leg and bladder with partial motor and complete bladder recovery in 2 months	Relief while followed, 2 months.
11. William D. MGH U-121679 Dr. J. S. Hodgson	64	Recurrent carcinoma rectum with nodules in perineal scar.	Perineal pain. Intrathecal alcohol block without benefit.	11/38	T1° C8°	L. R.	L2 T11	None.	Relief at discharge. Died within a year.
12. John M. MGH U-89570 Dr. J. J. Michelsen	47	Inoperable carcinoma rectum with metastases to lungs and lumbosacral plexus.	R. hip and leg.	6/38	T1° T2°	L. R.	••	Bronchopneumonia.	Relief to death at 1 mo
13. Stephen B. MGH U-210579 Dr. J. J. Michelsen	44	Recurrent carcinoma rectum in perineal scar.	Perineum.	9/39	T2° T3°	Bilat.	T5 T6	Mild incisional sepsis with transitory bladder weakness.	Relief at discharge. Death at 3 mos.
14. Felix B. MGH U-254556 Dr. J. S. Hodgson	60	Inoperable carcinoma sigmoid with liver and pelvic metastases.	Back, perineum, and legs.	5/41	T1 C7	L. R.	T10 Bilat.	Poor healing of incision. Transitory paresis R. leg.	Relief of pain while followed, 10 mos.
15. Helen F. MGH U-91091	44	Recurrent carcinoma rectum with invasion lumbosacral plexus.	Back and left leg.	10/10/41	T1°	R.	T6	None.	Complete relief on L. side. Bilateral relief to death, about 17 mos.
			Pain on R. after first cordotomy.	11/5/41	T2°	L.	T5		
16. Pauline O. MGH U-328619 Dr. J. S. Hodgson	43	Inoperable carcinoma rectum with pelvic metastases and invasion lumbosacral plexus.	Pelvic and bilateral leg pain.	11/41	T1 T2	R. L.	T9 Bilat.	None.	Relief on discharge. Died at 8 mos.
17. Maurice S. MGH U-161976	58	Recurrent carcinoma rectum with invasion lumbosacral plexus	R. back and leg.	11/41	T2°	L.	••	Transitory urinary retention cured by dilation of urethral stricture.	Relief to death at 2 mos.
18. Jerome V. MGH U-274555 Dr. J. S. Hodgson	54	Recurrent carcinoma rectum with pelvic metastases. Severe retention following abdominal perineal resection.	Low back and perineum.	4/3/42	T2° T1°	Bilat.	T7 Bilat.	*Catheter drainage on discharge.*	Relief on L. but level fell with recurrence on R.
				5/2/42	T3	L.	T7 R.		Relief to death at 5 mos.
). Charles K. MGH U-383567 Dr. J. J. Michelsen	59	Inoperable carcinoma rectum with pelvic metastases.	L. hip with postoperative onset right-sided pain	11/25/42 12/2/42	T2° T1	R. L.	T8	None.	Fair to death at 4 mos.
. Dorothea B MGH U-500033	34	Recurrent carcinoma rectum with pelvic metastases.	R. buttock, thigh, and lower leg. Recurrent left-sided pain.	10/45	T1°	L.	T11	R. foot drop.	
				12/45	T4°	R	T10		*Satisfactory relief to death at 15 mos.*

. George M. MGH U-517060	44	Recurrent colloid carcinoma rectum with perineal nodules and pelvic invasion.	L. leg and groin.	11/46	T2*	R.	L2	Mild wound sepsis.	Relief on L. 4 mos., followed by similar pain on R.
				2/47	T5*	L.	T7	Retention of urine relieved by transurethral resection of tumour at bladder neck.	Relief on discharge. Wife reports no pain to death after 2 mos.
22. Christian N MGH U-229887	73	Recurrent carcinoma sigmoid.	L. pelvis.	2/47	T4*	R.	T5	None.	Satisfactory to death at 7 mos.
23. Isabelle L. MGH U-558558	55	Recurrent carcinoma rectum with pelvic metastases.	R. pelvis and buttock, with postoperative pain on L.	3/47	T3*	L.	T11	Phlebitis and small pulmonary infarct.	Brief relief on R.
				5/47	T2*	R.	T8	Urgency and urinary incontinence.	Relief on L.
				6/47	T1*	L.	T8		Complete relief to death at 3 mos.
24. Sarah S. MGH U-547602	68	Recurrent colloid carcinoma sigmoid with abdominal metastases.	L. side of abdomen.	3/47	T2*	R.	T7	Slight weakness of R. leg.	Relieved. Developed less severe right-sided pain with obstruction. Died 9 wks.
25. Adrian P. MGH U-240258	49	Recurrent carcinoma rectum with invasion of perineal scar.	L. pelvis and thigh.	1/47	T2*	R.	T12	None.	Relief on L. with only mild discomfort on R. Died at 8 wks.
26. Alfred G. MGH U-465935	59	Recurrent adenocarcinoma sigmoid.	Pelvis and perineum, radiation to legs	5/47	T2* T4*	L. R.	T11 T11	Transitory paresis of bladder and legs.	Temporary relief only. Pain spread to other areas. Death at 17 mos.
27. Edward K MGH U-472726	52	Recurrent carcinoma sigmoid with local metastases in pelvis and scrotum.	Bilateral pelvic and scrotal pain.	1/48	T2* T4*	R. L.	T6 T7	Inlying catheter to death.	Relieved except for mild discomfort during episodes of intermittent obstruction. Death at 2 mos.
28. Catherine O. MGH U-601361	52	Recurrent adenocarcinoma rectum with extradural metastases in lumbosacral canal.	Perineum and legs, not relieved by decompressive laminectomy 1/3/48.	1/7/48	T2* T4*	R. L.	T10 T7	Required catheter for 3 wks., then incontinence from caudal paralysis. Precipitate urination without residual.	Complete relief. Died at 5½ mos.
29. Marjorie T. MGH U-134439	24	Recurrent carcinoma rectum with metastases in pelvis and lumbosacral plexuses.	R. sciatica.	4/20/48 5/10/48	T3* T2*	R. L.	T4 Hypalgesia T6	Increasing leg weakness which was probably due to nerve invasion by malignant cells.	Failure to achieve complete analgesia. Relieved for 3 mos., then developed burning pain in sacral decubitus, though less severe.

*Sensory level verified at operation.
**Adequate information not available in hospital records.

amination of Table XXXVIII will show that effective relief was obtained in 22 out of 25 cases. In 20 the tracts were cut bilaterally, in five others only on a single side. In one of the latter the successful result was vitiated by the development of pain on the opposite side. The three failures occurred in Patients 7, 26, and 29. In the first two, although the initial level appeared adequate, new lesions developed and pain spread to higher levels. In Patient 29 there was nearly complete absence of pain perception as high as the fourth and sixth thoracic segments. A casual observer might easily have mistaken this high grade hypalgesia for a complete interruption, but rapid repetitive pricking with a pin demonstrated some intact appreciation of sharpness over wide areas, indicating that pain-conducting fibres must have remained intact.

After 20 bilateral sections of the anterior quadrants there were 10 patients who required catheterization for longer than the usual seven to 10 day period. In all but three ability to empty the bladder at will and without excessive residual was being regained at discharge. Patient 21 required transurethral resection of the bladder neck. Only three had a prolonged disturbance of bladder control. Prolonged retention in the days before the discovery of antibiotics proved to be a really serious matter in Patient 7, in whom cystitis and ascending pyelonephritis led to ultimate fatality after discharge from the hospital. In Patients 8 and 21 retention was due in large part to invasion of the bladder wall by tumour. The latter case is cited in some detail because of its illustrative value:

Patient 21, George M., MGH U-517060, 44, had had an abdominoperineal resection on the surgical service nine months previously for extensive colloid carcinoma of the rectum. Seven months later a recurrent nodule had been removed from the perineal scar. He entered the hospital a third time for relief of severe pain in his left leg and groin. A right-sided cordotomy was performed on 11/6/46, following which he had mild postoperative atelectasis and incisional sepsis. Postoperative cystometrogram was normal and he was relieved of his left-sided pain. Shortly thereafter, however, pain developed in his coccyx. There was no x-ray evidence of sacral metastasis, but the pain soon radiated down his right leg and became so severe that it could not be controlled by medication. Left-sided spinothalamic tract section was therefore carried out on 2/10/47. The patient was very cooperative, and sensory testing first showed a level at T12. After three deeper and more anterior divisions of the tract the level had risen to T9. This time his postoperative course was complicated by a brief weakness of the left leg and an atonic bladder. Cystometrogram first showed no reflex contractions of the detrusor muscle and a low tone on filling. Cystoscopic examination on the urological service visualized an obstruction of the bladder outlet by tumour tissue. After this was resected he was able to void with only a moderate residual.

At discharge a month after operation he had complete relief of pain and was planning to return to work.

Weakness of the leg on account of injury to the contiguous pyramidal tract was a complicating factor in four patients, but this was always a transitory disability and did not long interfere with locomotion. Other postoperative complications consisted of phlebitis with a small pulmonary infarction in Patient 23, mild incisional sepsis in Patients 13 and 21, and bronchopneumonia in Patient 12.

In a recent article Krause and Lubert (1952) have pointed out that malignant disease of the large bowel is likely to lead to complicating compression of the ureters, especially the left one. Ureteral obstruction from malignant invasion of the paravertebral lymphatics has long been known to occur in uterine cancer. These authors record five cases with obstruction of one or both ureters in carcinoma of the rectum and sigmoid. Constriction of the ureter on the left is particularly likely to occur because the attachment of the mesocolon lies directly over its lower portion, which may be compressed by lymph nodes invaded by the growth. We have seen this happen twice in patients who had been successfully relieved of their pain by cordotomy. One died in uraemia before he could leave the hospital. In the other a symptomless nonfunctional left kidney had been previously diagnosed by intravenous pyelography. After his spinal operation he developed a low-grade painless fever. Pus found on retrograde pyelography led to resection of a pyonephrotic kidney, followed by favourable convalescence.

5. Tumours of the Kidney

In three patients with renal tumours, a carcinoma, sarcoma, and hypernephroma, pain developed in the terminal stages following metastasis to vertebrae, rib, and ilium (Table XXXIX). Attempts at palliative radiation proving fruitless and their pain being exceedingly severe, they were transferred to the neurosurgical service. In Patient 2, where x-ray examination revealed a collapse of the twelfth thoracic and first lumbar vertebrae, a decompressive laminectomy was first carried out without benefit. Bilateral anterolateral cordotomy was then performed without complication and with striking relief. She died two months later at home. In the other two cases, where paravertebral and iliac metastases produced one-sided pain, section of the contralateral spinothalamic tract gave satisfactory results. A fourth patient, whose renal carcinoma metastasized to the bladder, is included in the section below because the vesical lesion appears to have been the cause of his complaints. Cases of chronic renal pain of nonmalignant origin do not require cordotomy, as they can be dealt with so effectively by sympathetic denervation (see Chapter XX).

amination of Table XXXVIII will show that effective relief was obtained in 22 out of 25 cases. In 20 the tracts were cut bilaterally, in five others only on a single side. In one of the latter the successful result was vitiated by the development of pain on the opposite side. The three failures occurred in Patients 7, 26, and 29. In the first two, although the initial level appeared adequate, new lesions developed and pain spread to higher levels. In Patient 29 there was nearly complete absence of pain perception as high as the fourth and sixth thoracic segments. A casual observer might easily have mistaken this high grade hypalgesia for a complete interruption, but *rapid repetitive pricking with a pin demonstrated some intact appreciation* of sharpness over wide areas, indicating that pain-conducting fibres must have remained intact.

After 20 bilateral sections of the anterior quadrants there were 10 patients who required catheterization for longer than the usual seven to 10 day period. In all but three ability to empty the bladder at will and without excessive residual was being regained at discharge. Patient 21 required transurethral resection of the bladder neck. Only three had a prolonged disturbance of bladder control. Prolonged retention in the days before the discovery of antibiotics proved to be a really serious matter in Patient 7, in whom cystitis and ascending pyelonephritis led to ultimate fatality after discharge from the hospital. In Patients 8 and 21 retention was due in large part to invasion of the bladder wall by tumour. The latter case is cited in some detail because of its illustrative value:

Patient 21, George M., MGH U-517060, 44, had had an abdominoperineal resection on the surgical service nine months previously for extensive colloid carcinoma of the rectum. Seven months later a recurrent nodule had been removed from the perineal scar. He entered the hospital a third time for relief of severe pain in his left leg and groin. A right-sided cordotomy was performed on 11/6/46, following which he had mild postoperative atelectasis and incisional sepsis. Postoperative cystometrogram was normal and he was relieved of his left-sided pain. Shortly thereafter, however, pain developed in his coccyx. There was no x-ray evidence of sacral metastasis, but the pain soon radiated down his right leg and became so severe that it could not be controlled by medication. Left-sided spinothalamic tract section was therefore carried out on 2/10/47. The patient was very cooperative, and sensory testing first showed a level at T12. After three deeper and more anterior divisions of the tract the level had risen to T9 This time his postoperative course was complicated by a brief weakness of the left leg and an atonic bladder. Cystometrogram first showed no reflex contractions of the detrusor muscle and a low tone on filling. Cystoscopic examination on the urological service visualized an obstruction of the bladder outlet by tumour tissue. After this was resected he was able to void with only a moderate residual

TABLE XL

TUMOURS OF BLADDER (6 CASES)

Patient	*Age*	*Tumour - Type and Location*	*Pain Reference*	*Date*	*Level of Cordotomy*	*Side*	*Sensory Level*	*Complications*	*Result*
Spinothalamic Tractotomy									
1. Walter R. MGH U-13908	56	Inoperable squamous cell carcinoma of bladder.	Suprapubic, bilateral.	3/37	T2* T3*	L. R.	L1 T10	None. Voided on second day.	Satisfactory relief while followed, 3 wks.
2. William J. MGH U-251082 Dr. J. J. Michelsen	55	Inoperable carcinoma bladder with diffuse pelvic and L. paravertebral extension.	L. pelvis and leg, not relieved by two previous subarachnoid alcohol injections.	5/41	T2	R.	**	Massive haemorrhage from bladder.	Died of disease on 4th day.
3. Frank P. MGH U-332849	50	Inoperable carcinoma L. side of bladder with bilateral ureterostomies.	Suprapubic and deep in pelvis.	3/42	T2* T3*	L. R.	T7 T7	R. pulmonary atelectasis.	Complete relief at discharge. Died 1 mo.
4. John R. MGH U-259202 Dr. J. J. Michelsen	48	Inoperable carcinoma bladder with L. pelvic extension.	L. hip and leg.	8/42	C2	R.	**	None.	Relieved at discharge but required morphine twice a day during 2 mos. period of survival.
5. Lester S. MGH U-506841 Dr. W. J. Mixter	40	Inoperable sarcoma L. kidney with extension to bladder.	Burning pain L. groin with sciatic radiation, which shifted to R. side after first cordotomy.	1/46	T2*	R.	T7	None.	
				3/46	T1*	L.	T8		Complete relief but rapid downhill course with chyloascites. Died at 1 mo.
6. Irving P. MGH U-555399	50	Advanced carcinoma bladder with pelvic extension, blocked ureter and ureterostomy	Penis, perineum, R. flank, and both thighs.	7/47	T3* T1*	R. L.	T7 T9	None.	Complete relief at discharge. Late return of pain on one side from fall in level of analgesia. Died 7 mos.

*Sensory level verified at operation.
**Inadequate information available in hospital records.

TABLE XXXIX

TUMOURS OF KIDNEY (3 CASES)

Patient	*Age*	*Tumour - Type and Location*	*Pain Reference*	*Date*	*Level of Cordotomy*	*Side*	*Sensory Level*	*Complications*	*Result*
Spinothalamic Tractotomy									
1. Otto K. MGH U-29379 Dr. J. S Hodgson	54	Recurrent carcinoma kidney with metastases in T10 vertebra and ninth rib.	Back, R. chest, and legs.	6/39	C5*	R.	T4	None.	Complete relief at discharge and family felt operation was helpful. Died at 2¼ mos.
2. Sarah M. MGH U-299213 Dr. J. S. Hodgson	67	Inoperable R hypernephroma with metastases T12 and L1 vertebrae.	R. costovertebral region unrelieved by decompressive laminectomy.	5/41	C5 C8	R. L.	T6	None, except for bladder paralysis which antedated cordotomy.	Complete relief at discharge. Died at 2 mos.
3 Peter B. MGH U-527244	46	Sarcoma L. kidney with metastases to L. ilium.	L. flank and testicle.	4/46	T1*	R.	T5	Large residual urine at discharge.	Complete relief at discharge, but is reported to have required narcotics later, due to right-sided pain. Died at 1 mo.

*Sensory level verified at operation.

A radical transection of the left spinothalamic tract was carried out on 12/23/46, but as he could not be shifted from his bed to the operating table without a general anaesthetic ether had to be used.* This is contrary to our usual policy and prevented sensory testing in the course of the operation, but on recovery he was found to have analgesia to T8, with complete relief of right-sided pain. There was no weakness of his ipsilateral leg and he was able to move the right again. Twelve days later normal micturition was re-established, but he was then complaining bitterly of pain in the left side of his pelvis and left leg. From only a minimal amount of discomfort on this side before the cordotomy pain had increased to an unbearable degree. We have seen this occur on a number of occasions, as the severe pain on one side may mask the lesser discomfort in the opposite extremity. Orchidectomy was performed on the urological service, but without any palliative effect. Therefore right spinothalamic tractotomy was undertaken on 1/22/47. On this occasion again the sensory level could not be tested on the operating table. The level of analgesia was complete only to L2 with hypalgesia to T11, but nevertheless relief of pain was complete. A cystometrogram made on the twelfth day showed return of normal bladder tone and sensation, so the inlying catheter was removed and he was able to empty the bladder well. Unfortunately continued growth of the tumour soon resulted in an increasing amount of residual urine with eventual infection. He died at home four months after his second operation.

A single example of painful testicular tumour, a recurrent embryoma, is included with this series. This 32-year-old male (Patient 9) suffered severely from pain because of metastases in his groin and pelvis. He had the added unusual feature of a painful sensation in the amputated testicle, an interesting variety of postamputation phantom recently described by Heusner (1950). Both the pain from his metastases and the phantom disappeared after a high cervical cordotomy. His postoperative recovery was uneventful and he was able to work for a brief period before his rapid demise six weeks later.

8. Tumours of the Uterus and Female Genital Tract

Carcinoma of the female genital tract, in our experience, has been the most common cause of unbearable pain requiring neurosurgical intervention. Thirty-seven examples are available for evaluation after anterolateral cordotomy. In 26 of these the original focus was in the cervix. Carcinoma arising in this area is most likely to invade the lateral walls of the pelvis and ascend via the regional lymphatics along the paravertebral gutters to involve

*To-day this patient would be put to sleep in his bed with a minimal dose of Pentothal supplemented by nitrous oxide or Trilene. After transfer to the operating table infiltration of procaine in the area of incision would permit his being awakened for testing of the sensory level.

6. Tumours of the Bladder

Six painful malignant tumours of the bladder, summarized in Table XL, have been encountered in which invasion of somatic nerves in the lateral pelvic wall made cordotomy the method of choice for interruption of sensory pathways. *In the four patients in whom the tracts were cut bilaterally, the* pain in the suprapubic region, pelvis, and legs was relieved. In one, Patient 6, however, there was a late recurrence due to a drop in the sensory level on one side. Of the two with unilateral leg and hip pain, section of the contralateral tract in Patient 4 was a success, but Patient 2 succumbed to massive haemorrhage from the bladder too soon for evaluation. Aside from death from disease in this case and a temporary postoperative atelectasis in Patient 3, there were no complications.

7. Tumours of Prostate and Male Genitalia

Carcinoma of the prostate, with its tendency to stretch periosteum after metastasizing to bone and also to invade the large nerve trunks in the lateral pelvic wall, is one of the tumours that most frequently give rise to unbearable pain. Except for the fact that its radiation is usually bilateral, the distribution of this pain over lower lumbar and sacral dermatomes is most favourable for relief by cordotomy. The palliative response should be excellent provided the surgeon will take the trouble to check the level of his section on the operating table.

Eight of these cases are summarized in Table XLI. The degree of local relief was most gratifying in every instance, although Patient 2 subsequently developed thoracic metastases which were painful. All but one required bilateral section of the anterolateral columns. As to complications, Patient 7 complained of radicular pain at the level of his incision and still required an inlying catheter at discharge six weeks after operation. He also suffered a paresis of the left leg, but its exact extent was difficult to evaluate because of his advanced cachexia and general weakness. The others treated with bilateral operations had no involvement of the pyramidal tract and soon regained normal control of their bladders, Patient 8 as early as the fourth day after operation and Patient 6 on the twelfth. The latter, on account of his unusually severe pain and good postoperative result, is an interesting case to discuss in further detail.

Patient 6, Peter B., MGH U-558292, 56, was referred to us by Dr. George Speare for pain with inoperable carcinoma of the prostate. Hormone therapy had failed to give him relief. He was bedridden and unable to move his right leg because of agonizing pain on any movement of the hip. Left-sided pain of milder degree was present as well. X-rays showed metastatic foci in both ilia and also in his eighth thoracic vertebra.

A radical transection of the left spinothalamic tract was carried out on 12/23/46, but as he could not be shifted from his bed to the operating table without a general anaesthetic ether had to be used.* This is contrary to our usual policy and prevented sensory testing in the course of the operation, but on recovery he was found to have analgesia to T8, with complete relief of right-sided pain. There was no weakness of his ipsilateral leg and he was able to move the right again. Twelve days later normal micturition was re-established, but he was then complaining bitterly of pain in the left side of his pelvis and left leg. From only a minimal amount of discomfort on this side before the cordotomy pain had increased to an unbearable degree. We have seen this occur on a number of occasions, as the severe pain on one side may mask the lesser discomfort in the opposite extremity. Orchidectomy was performed on the urological service, but without any palliative effect. Therefore right spinothalamic tractotomy was undertaken on 1/22/47. On this occasion again the sensory level could not be tested on the operating table. The level of analgesia was complete only to L2 with hypalgesia to T11, but nevertheless relief of pain was complete. A cystometrogram made on the twelfth day showed return of normal bladder tone and sensation, so the inlying catheter was removed and he was able to empty the bladder well. Unfortunately continued growth of the tumour soon resulted in an increasing amount of residual urine with eventual infection. He died at home four months after his second operation.

A single example of painful testicular tumour, a recurrent embryoma, is included with this series. This 32-year-old male (Patient 9) suffered severely from pain because of metastases in his groin and pelvis. He had the added unusual feature of a painful sensation in the amputated testicle, an interesting variety of postamputation phantom recently described by Heusner (1950). Both the pain from his metastases and the phantom disappeared after a high cervical cordotomy. His postoperative recovery was uneventful and he was able to work for a brief period before his rapid demise six weeks later.

8. Tumours of the Uterus and Female Genital Tract

Carcinoma of the female genital tract, in our experience, has been the most common cause of unbearable pain requiring neurosurgical intervention Thirty-seven examples are available for evaluation after anterolateral cordotomy. In 26 of these the original focus was in the cervix Carcinoma arising in this area is most likely to invade the lateral walls of the pelvis and ascend via the regional lymphatics along the paravertebral gutters to involve

*To-day this patient would be put to sleep in his bed with a minimal dose of Pentothal supplemented by nitrous oxide or Trilene After transfer to the operating table infiltration of procaine in the area of incision would permit his being awakened for testing of the sensory level

Table XLI

TUMOURS OF PROSTATE AND MALE GENITALIA (9 CASES)

Patient	*Age*	*Tumour - Type and Location*	*Pain Reference*	*Date*	*Level of Cordotomy*	*Side*	*Sensory Level*	*Complications*	*Result*
SPINOTHALAMIC TRACTOTOMY									
A. *Prostate:*									
1. Herbert C. BM #24918 Dr. W. J. Mixter	67	Carcinoma prostate.	R. leg.**	8/36	T3	L.	**	None. Had required catheterization for over a year on account of growth.	Relief on discharge. Died in 1937.
2. John H. BM #45795 Dr. J. S Hodgson	63	Carcinoma prostate with pelvic metastases.	Low back, buttocks, and legs.	5/37	C7* T1*	R. L.	**	**	Relief, but developed pain from chest metastases. Died 3 mos.
3. Norman S. MGH U-55429 Dr J. S. Hodgson	66	Carcinoma prostate with multiple bony metastases. Arteriosclerosis, hypertension, and chronic nephritis.	Lumbar spine and both hips, not relieved by subarachnoid injection of alcohol.	2/38	C7* T1*	R. L.	T9 T10	None.	Relief at discharge. Died within year.
4. Philip S MGH U-151698 Dr J. J. Michelsen	72	Carcinoma bladder, recurrent after operation, with pelvic metastases.	Lumbosacral region, lower abdomen, and L. leg.	12/43	T2 T4	R. L.	T8 T10	Retention of urine, discharged with inlying catheter. Constipation. Moderate paresis L. leg.	Complete relief to death in 1 mo.
5. Eliot P. MGH U-527444 Dr. W. J. Mixter	66	Carcinoma prostate with diffuse metastases in pelvic bones.	Mid-dorsal spine and L. sciatic nerve, with later shift to R. leg.	1/18/46 5/8/46	T2* T1*	R. L.	T6 T7-L3	Some pleuritic pain at discharge.	Pain in back and legs relieved at discharge, but pain is reported to have recurred in L. leg. Died within yr.
6. Peter B. MGH U-558292	56	Carcinoma prostate with metastases to ilium and upper femur, with compression fracture of vertebra.	Excruciating pain on any movement R. hip, with much less on L.	12/46	T3	L.	Analgesia T8	None.	Complete relief, but pain on L. became more severe.
				1/47	T2*	R.	Analgesia L2	Normal cystometrogram and voiding in 12 days.	Complete relief to death at 4 mos.

7. Earle S. MGH U-457104 Dr. H. T. Ballantine	66	Carcinoma prostate with metastases in perineum and bladder.	Back and L. hip.	4/48	T1* T3*	L. T6 R. T8	Much incisional pain, and urinary retention from local disease.	Satisfactory relief at death at 3½ mos.
8. Thomas W. MGH U-457104	67	Carcinoma prostate with osteoblastic metastases L. spine, pelvis, and ribs	L leg, with onset of severe R. leg pain day after first cordotomy.	7/48	T3* T2*	R. T7 L. T5	Voided normally in 4 days.	Relief on discharge. No follow-up.
B. Testicle:								
9. Ralph H. MGH U-395116 Dr. J. S. Hodgson	32	Recurrent embryoma of testicle following amputation with metastases in L. groin and retroperitoneal area.	L. groin, pelvis, and back with phantom sensation of missing L. testicle	4/43	C2*	R. C5	None.	Complete relief of local and phantom pain. Returned to work at 1 mo. In last 2 wks. of life developed mild pain on R. Died at 13 mos.

*Sensory level verified at operation.
**Inadequate information available in hospital records.

the trunks of the lumbosacral plexus. With this route of invasion there is often added lymphoedema of the leg or ureteral obstruction with destruction of the kidney. Compression of the nerve trunks may lead to paralysis, but the hypaesthetic leg is likely to become extremely painful. Metastases to the pelvic bones and vertebrae are less frequent causes of back and abdominal pain.

Inasmuch as the mechanism and distribution of pain is the same regardless of whether the disease develops in the uterine fundus, cervix, or vagina, the statistical results which are broken down in Table XLII are summarized here as a single group. The results, as might be expected with pain situated low in the pelvis and sciatic distribution, are excellent. Following 19 bilateral and 18 unilateral transections of the spinothalamic tract satisfactory relief of the original pain was obtained in 33 patients. There were only four failures because of early inadequate levels of analgesia (Patients 6, 15, 27, and 32). After unilateral operations pain frequently became severe on the opposite side, but this was again relieved by secondary cordotomy in four. In Patents 3 and 27 the initial sensory levels were sufficient to relieve the original pain radiating to the pelvis and legs, but not the subsequent discomfort from upward extension of the growth.

Complications related directly to cordotomy consisted of annoying paraaesthesiae in the analgesic legs in Patients 7, 12, and 14; retention of urine, which was still a troublesome factor at discharge in four others (Patients 3, 20, 30, and 37); and leg weakness in two (Patients 14 and 20). Another woman, Patient 17, who developed an increase in her pre-existent bilateral leg weakness, which recovered in six weeks, is of interest to report in further detail because of the transitory hypotension that occasionally follows transection of both anterolateral columns:

Patient 17, Mrs. Catherine T., MGH U-196119, 41, was admitted to the neurosurgical service after four previous entries for Grade III epidermoid carcinoma of the cervix uteri. She had had radium and x-ray treatment, a right saphenous vein ligation with lumbar sympathectomy for painful phlebitis, and a nephrostomy. Paraparesis was already present. Pain was severe and radiated from the pelvis to both legs. Bilateral anterolateral cordotomy was carried out on 3/6/42 under local anaesthesia with establishment of a sensory level at T7, which was well maintained. For the first three days after operation her blood pressure remained at a shock level (80/50), but without any other evidence of circulatory failure. This was accompanied by pronounced vasodilatation of the trunk and legs and resembled the type of hypotension often seen in spinal anaesthesia. It cleared without any deleterious effect. There was no evidence of urinary retention, although she had serious weakness of both legs. This was well on the road to recovery at six weeks, when we received an enthusiastic follow-up letter from her husband, "She feels no

TABLE XLII

TUMOURS OF UTERUS AND FEMALE GENITALIA (37 CASES)

Patient	Age	Tumour - Type and Location	Pain Reference	Date	Level of Cordotomy	Side	Sensory Level	Complications	Result
SPINOTHALAMIC TRACTOTOMY									
A. *Uterus (5 cases).*									
1. Margaret H. BM #21579	43	Recurrent carcinoma uterus with bony metastases in ilium.	R lower abdomen and leg.	1/36	T3*	L.	T11	None.	Relief at discharge. Died at 3½ mos.
2. Helga B. MGH U-1098 Dr. W. J. Mixter	59	Recurrent carcinoma uterus with invasion lumbosacral plexus and paravertebral lymphatics.	R. lower abdomen and leg	1/37	T1	L.	T10	R. lymphoedema.	Relief at discharge, but later developed left-sided pain. Followed 3 mos.
3. Louise P. MGH U-146030 Dr. W. J. Mixter	53	Recurrent carcinoma uterine fundus.	Back, L. buttock, groin, and thigh. Slight pain in R. thigh.	8/38	T3* T1*	R. L.	T5 T6	Hypotension requiring two transfusions. Phlebitis. Urinary retention persisted at discharge.	Original pain relieved, but general condition deteriorated. Many complaints. Pain developing in R. arm when last seen at 2 mos.
4. Maude G MGH U-28938 Dr. J J Michelsen	70	Recurrent adenocarcinoma uterus	R. leg.	7/43	T2	L.	T6	Transitory weakness L. leg and bladder.	Relief. Moderate pain on L. Died at 1½ mos.
5. Sarah J. MGH U-418613 Dr W. J. Mixter	63	Recurrent carcinoma uterine fundus with vaginal and pelvic metastases.	L. buttock radiating down sciatic nerve.	11/45	T1*	R.	T7	Myocardial infarct. Morphine withdrawal symptoms.	Relief at discharge. Pain on other side became troublesome after a year and severe at 18 mos. Death at 2 yrs.
B. *Cervix (26 cases).*									
6. Nora M. MGH #350646	60	Carcinoma cervix with L. pelvic mass	Low back and L. leg.	1/36	T2* T3*	R. L.	T10 0	None.	Failure on L. side where tract was incompletely cut *** Died at 3 mos.
7. Thea W. MGH U-1179 Dr. J. S. Hodgson	48	Carcinoma cervix with pelvic metastases.	Pelvis and R. leg. Onset of left-sided pain after first cordotomy.	1/37	C6*	L.	T8	None.	Relief on R.
				3/37	C3*	R.	**	Burning paraesthesia in analgesic area.	Relief of former symptoms on L. but developed burning pain. Followed 6 wks.

Table XLII

TUMOURS OF UTERUS AND FEMALE GENITALIA (37 CASES)—Continued

Patient	*Age*	*Tumour - Type and Location*	*Pain Reference*	*Date*	*Level of Cordotomy*	*Side*	*Sensory Level*	*Complications*	*Result*
Spinothalamic Tractotomy									
8. Lillian H. MGH U-23976	48	Carcinoma cervix with involvement lumbosacral plexuses and L3 vertebra.	Pelvis and legs.	4/37	T2* T3*	R. L.	T10 T11	Normal micturition after 8 days and out of bed. Onset of uraemia at 10 days.	Complete relief. Died at 18 days of bilateral ureteral occlusion with added thrombosis of vena cava, psoas abscess, and septicaemia.
9. Violet S MGH U-89254	28	Carcinoma cervix.	Low back.	2/38	T1* T2*	R. L.	T7 T8	Transitory urinary retention requiring tidal drainage.	Relief. Died at 3 mos., pain-free, of haemorrhage.
10. Anita D. MGH U-36533	49	Carcinoma cervix with invasion of bladder and rectum	Pain in R. leg not relieved by two intrathecal injections of alcohol.	4/38	T3*	L.	T8	None except for continued vaginal bleeding.	Complete relief 1 mo Later required codeine only. Died within year.
11. Loretta M. MGH U-221731 Dr. J. S. Hodgson	44	Carcinoma cervix with invasion of lumbosacral plexus of L. side of pelvis and pulmonary metastasis.	Sciatic radiation L. leg not relieved by intrathecal injection of alcohol.	12/39	C7	R.	T5	Transitory weakness of bladder followed in 3 mos. by paraplegia, urinary infection and L. pelvic abscess. Died of sepsis.	Complete relief left-sided pain, but developed pain on R. Died at 6 mos.
12. Mildred B. MGH U-296027 Dr. J. S. Hodgson	49	Recurrent carcinoma cervix in pelvis and groin.	L. leg with sciatic radiation.	7/41 8/41	C8 T1	R. L.	T5 T5	Mild unpleasant hot sensation in legs.	Increasing paralysis from nerve compression, yet relieved of pain till moribund at 3½ mos.
13. Irene R. MGH U-323375	37	Carcinoma cervix with masses R. pelvis and groin. Hydroureter.	R hip and leg.	10/41	T2*	L.	T6	None.	Complete relief to death at 1 mo.
14. Lillian Br. MGH U-213542	48	Carcinoma cervix with extensive pelvic metastases. Bilateral hydronephrosis and ureterostomies.	L. lower back with radiation to abdomen, perineum and posterior thigh.	10/41	T1* T2*	R. L.	T6 T6	Bilateral partial paralysis of legs with paraesthesia of feet.	Relief to death at 3½ mos. but suffered severely from paraesthesia.
15. Margaret P. MGH U-325554	45	Recurrent carcinoma cervix with occlusion R. ureter and invasion lumbosacral plexus.	R. sciatic pain which simulated ruptured intervertebral disc.	12/41	T3	L.	T12 falling to L2	None.	Failure due to inadequate level. Improved by later intrathecal injection of alcohol. Followed 7 mos.

16. Josephine D. MGH U-35187 Dr. J S. Hodgson	56	Carcinoma cervix with metastases to lumbar spine and retroperitoneal tissues.	L pelvis and both legs.	1/12	T1 T2	R. L.	••	Uraemic coma.	Death from disease at 19 days.
17. Catherine T. MGH U-196110	41	Carcinoma cervix with paravertebral invasion and ureteral obstruction treated by nephrostomy. Preoperative paraparesis.	Pelvis and both legs.	3/12	T2* T3*	L. R.	T7 T7	Blood pressure 90/50 for 3 days without evidence of shock. Pronounced weakness of legs, which recovered to preoperative level.	Effective relief while followed for 8 mos.
18. Gladys M. MGH U-242809	45	Carcinoma cervix with metastases to pelvic bones and inguinal nodes.	L. hip and thigh.	4/12	T4*	R.	T8	None.	Relief to death at 3 mos.
19. Alberta R. MGH U-351311 Dr. W. J. Mixter	50	Carcinoma cervix with invasion of lumbosacral plexus.	R sciatic pain.	5/12	T2*	L.	T10	None.	Relief at discharge. Died within year.
20. Anna R. MGH U-322778 Dr. J. J. Michelsen	36	Carcinoma cervix with metastases to lumbar vertebrae and cauda equina.	Back and R. leg.	8/12	C2	L.	C3	Low grade wound sepsis. Paresis L. arm and leg with prolonged urinary retention. Developed general carcinomatosis.	Relief of right-sided pain, but pain spread to L. side. Died at 2 mos.
1. Norma N. MGH U-401605 Dr. J. S. Hodgson	32	Carcinoma cervix with pelvic invasion and occlusion L. ureter. Compression of sciatic roots.	Pelvis and both legs.	5/13	T2 T3	L. R.	0 T8	Urinary difficulty cleared in 9 days. Moderate leg weakness.	Relief at discharge, but pain recurred on R. with fall of analgesia. Death at 3 mos. from intestinal obstruction.
. Mary M. MGH U-263700	55	Carcinoma cervix with invasion rectum and bladder.	Rectum and vagina.	2/15	T2 T3	L. R.	T10 L1	Slight incontinence of urine.	Complete relief at discharge, but developed new pain at higher level prior to death at 2 mos.
Caroline S. MGH U-82877	42	Carcinoma cervix with pulmonary, bony, and pelvic metastases Swelling of paralyzed L. leg	L. pelvis and leg.	4/15	T2	R.	T5	None immediately. Late ureteral obstruction and cystitis from growth.	Relief of left-sided pain. Late development of pain on R. Death at 3 mos.

Table XLII

TUMOURS OF UTERUS AND FEMALE GENITALIA (37 CASES)—Continued

Patient	Age	Tumour - Type and Location	Pain Reference	Date	Level of Cordotomy	Side	Sensory Level	Complications	Result
SPINOTHALAMIC TRACTOTOMY									
24. Jennie S. MGH U-498663	47	Carcinoma cervix with pelvic metastasis.	R. sciatica simulating ruptured intervertebral disc. Negative local exploration	8/45	T1	L.	T3	None. Voided after fourth day.	Complete relief. Followed 3½ yrs.
25. Effie H MGH U-298147 Dr. W. J. Mixter	45	Carcinoma cervix with pelvic metastases. Block of L. ureter.	L. buttocks and leg with radiation to lower abdomen	9/45	T2*	R.	**	None.	Complete relief at discharge to death in 4 mos. Mild pain developed on opposite side.
26. Evelyn M. MGH U-547964 Dr. W. J. Mixter	36	Carcinoma cervix with L. ureteral obstruction and invasion of bladder	L. leg.	6/47	T1* T2*	R. L.	T9 T10	Increasing obstruction R. ureter and mass in bladder causing preoperative difficulty in urination.	Free of pain, no need of narcotics to death at 4 mos.
27. Gertrude W. MGH U-524230 Dr. H. T. Ballantine	47	Carcinoma cervix with pelvic invasion and paresis L. leg	Pelvis and both legs.	8/47	T1* T2*	R. L.	T9 T7	Normal micturition in 9 days	Pain relieved in legs at discharge, but recurred in abdomen. Followed 3 mos.
28. Ruth W. MGH U-367779 Dr. W. J. Mixter	49	Recurrent carcinoma cervix with oedema and weakness R. leg. Vertebral metastases L4 and L5.	Low back, abdomen, and L. sciatic radiation. Required 15 mgm. morphine to turn patient in bed.	8/47	T2-T3*	Bilat	T6	Weakness somewhat increased in L. leg. Urinary incontinence.	Relief to death at 3 mos.
29. Ida L. MGH U-527509	33	Carcinoma cervix with R pelvic invasion and blocked ureter. Paretic R leg	R L Q, back, and thigh.	10/47	T2*	L.	Hypalgesia T6 Analgesia T10	None.	Relief at discharge. No follow-up. Died 1918.
30. Lillian Ba. MGH U-494748	41	Carcinoma cervix with pelvic invasion.	Low backache radiating to L. thigh and groin. Later pain on R.	11/48	T3*	R.	T7	Required catheterization to discharge.	Relief on L.
				1/49	T4*	L.	T9		Relief on R. Followed 2 mos.
31. Edith L. MGH U-610902 Dr. W. J. Mixter	53	Recurrent carcinoma cervix with paralysis R. leg.	R groin and leg	3/48	T2*	L.	T6	None.	Relief at discharge, but developed higher chest pain and some in groin. Died within year

C. Ovary (1 case):									
32. Clara E. MGH U-253448	77	Carcinoma ovary with irritation lowest sacral nerve roots	Sacrum and anal areas.	3/47 4/47	T3* T4*	L. R.	L2 T10	None. Voided on third day but incontinence required inlying catheter for 2 wks.	No relief from burning perianal pain and suffered higher pain with late thoracic metastases. Death at 1 yr.
D Vagina (2 cases):									
33. Adelaide W. MGH U-189074 Dr. J. S. Hodgson	50	Carcinoma vagina with pelvic invasion and vesico-vaginal fistula.	Suprapubic area.	7/39	C7 C8	R. L.	T2 T2	None.	Relief at discharge. Died within year.
34. Priscilla R. MGH U-13756	68	Carcinoma vagina with invasion of rectum. Recurrence after combined abdominoperineal resection with metastases to inguinal and supraclavicular nodes.	R. pelvis and sciatic distribution.	6/41	T2*	L.	T6	None.	Relief at discharge with excellent result up to death at 1 yr.
E. Vulva (3 cases):									
35. Margaret S. MGH #345194	35	Carcinoma of vulva.	Pain in perineum and radiation to both legs.	5/35	T2 T3	R. L.	T8 0		Continued to have right-sided pain due to inadequate level.
				7/35	T3	L.	T8	Urination soon re-established but she continued to have occasional incontinence of bladder and rectum.	Relief while followed for 9 mos.
36. Malinde H. MGH U-135035 Dr. J. S. Hodgson	50	Carcinoma R side vulva with pelvic metastases.	R. pelvis and bladder with pain developing on L. after first cordotomy.	6/38	T1*	L.	**	None.	Relief on R.
				7/38	T2*	R.		Renal infection. Increasing cachexia with multiple bony metastases.	Relief on L. to death at 2 mos.
37. Mary B. MGH U-140688	52	Carcinoma vulva with pelvic and R.L.Q. metastases and oedema of legs.	R. pelvis and thigh.	9/48	T2*	L.	T9	Urinary retention at discharge required inlying catheter.	Relief to death at 4 mos.

*Sensory level verified at operation; in a small proportion of cases this could not be satisfactorily carried out.
**Inadequate information available in hospital records.
***When patient was tested on table it was observed that sensory level on L. rose only to T12 A second deeper section should have been made.

TABLE XLII

TUMOURS OF UTERUS AND FEMALE GENITALIA (37 CASES)—Continued

Patient	*Age*	*Tumour - Type and Location*	*Pain Reference*	*Date*	*Level of Cordotomy*	*Side*	*Sensory Level*	*Complications*	*Result*
SPINOTHALAMIC TRACTOTOMY									
24. Jennie S. MGH U-498663	47	Carcinoma cervix with pelvic metastasis.	R. sciatica simulating ruptured intervertebral disc Negative local exploration	8/45	T1	L.	T3	None. Voided after fourth day.	Complete relief Followed 3½ yrs
25. Effie H. MGH U-298147 Dr. W. J. Mixter	45	Carcinoma cervix with pelvic metastases. Block of L ureter.	L buttocks and leg with radiation to lower abdomen	9/45	T2*	R.	**	None.	Complete relief at discharge to death in 4 mos. Mild pain developed on opposite side.
26. Evelyn M. MGH U-517964 Dr. W. J. Mixter	36	Carcinoma cervix with L ureteral obstruction and invasion of bladder	L. leg.	6/47	T1* T2*	R. L.	T9 T10	Increasing obstruction R ureter and mass in bladder causing preoperative difficulty in urination	Free of pain, no need of narcotics to death at 4 mos.
27. Gertrude W. MGH U-524230 Dr. H. T. Ballantine	47	Carcinoma cervix with pelvic invasion and paresis L. leg	Pelvis and both legs.	8/47	T1* T2*	R. L.	T9 T7	Normal micturition in 9 days.	Pain relieved in legs at discharge, but recurred in abdomen. Followed 3 mos.
28. Ruth W. MGH U-367779 Dr. W. J. Mixter	49	Recurrent carcinoma cervix with oedema and weakness R. leg. Vertebral metastases L4 and L5	Low back, abdomen, and L. sciatic radiation. Required 15 mgm morphine to turn patient in bed.	8/47	T2-T3*	Bilat.	T6	Weakness somewhat increased in L leg. Urinary incontinence.	Relief to death at 3 mos.
29. Ida L MGH U-527509	33	Carcinoma cervix with R. pelvic invasion and blocked ureter. Paretic R leg.	R L Q , back, and thigh.	10/47	T2*	L.	Hypalgesia T6 Analgesia T10	None.	Relief at discharge. No follow-up. Died 1948.
30. Lillian Ba. MGH U-494748	41	Carcinoma cervix with pelvic invasion.	Low backache radiating to L. thigh and groin. Later pain on R.	11/48	T3*	R.	T7	Required catheterization to discharge.	Relief on L.
31. Edith L. MGH U-610902 Dr. W. J. Mixter	53	Recurrent carcinoma cervix with paralysis R. leg.	R. groin and leg.	1/49	T4*	L.	T9		Relief on R. Followed 2 mos.
				3/48	T2*	L.	T6	None.	Relief at discharge, but developed higher chest pain and some in groin. Died within year.

small branches of the anterior spinal artery that supply the pyramidal tract (see p. 249).

9. Tumours of Bone

This series of 16 cases, which are presented in Table XLIII, comprised a wide variety of bony neoplasms: sarcoma, chondrosarcoma, Ewing's and reticulum cell sarcoma, lymphoma, and carcinomatous metastases of unknown origin. Pain when tumours invade the ribs, pelvis, and long bones is usually brought about by stretching of periosteum, which is endowed with a very rich supply of sensory endings. In the case of the sacrum and vertebrae the pain is often produced by compression of the spinal roots.

In this series the results were good in 12 cases, although in Patients 9, 11, and 13 following a unilateral tractotomy the pain subsequently spread to involve the opposite side. It was possible to relieve pain from a chondrosarcoma of the right upper thoracic wall in Patient 3 by a deep incision of the contralateral spinothalamic tract at the second cervical vertebra, but he continued to complain considerably of pain at a higher level in the arm and shoulder. Patient 5, although apparently adequately relieved by a bilateral section, died of intestinal haemorrhage on the third day, too soon for certain evaluation.

There were two other deaths definitely related to cordotomy. The first occurred in a man (Patient 1) who was in desperate condition because of generalized metastases with excruciating pain in the lumbosacral region, pelvis, and right thigh, which was poorly controlled by doses of morphine every four hours. He died of bronchopneumonia in the pre-sulfa-penicillin era. In the second (Patient 14) it had been necessary to cut the spinothalamic tract in the medulla for osteogenic sarcoma of the shoulder with pulmonary metastases. On the first day he had a level of analgesia to his chin and his condition was satisfactory except for slight difficulty in swallowing. On the second day sudden death followed a generalized convulsion. This can best be explained by the hypothesis that medullary tractotomy near the level of the nucleus ambiguus is a dangerous proceeding in the presence of pre-existent vagal paralysis by a cervical growth. In all three of these patients who died relief of pain appeared to be complete, but the period of survival was too short to justify a definite evaluation. There was no more than a transitory retention of urine and weakness of the lower extremity in any except in Patient 4, where weakness of the bladder as well as the leg was present before operation and slightly increased by it.

10. Tumours of Skin, Fascia, and Muscle

This final group of nine cases comprises a variety of sarcomas arising from melanophores, connective and myxomatous tissue, *reticulum cell sar-*

pain in either leg . . . she has taken absolutely no narcotics since she came home . . . all in all I feel that she is in much better condition."

Two patients (Cases 8 and 16) died of their disease while in the hospital. Uraemia from ureteral compression and hydronephrosis was the responsible factor in each. Details of the former are of interest to report.

Patient 8, Lillian H., MGH U-23976, 48, was first admitted in 1934 with Grade III carcinoma of the cervix, which was biopsied and treated by radiation. Four months before her second hospital admission pain became severe in her lumbar spine and spread to her right leg. She was unable to stand erect because of back pain and leg weakness. When she failed to respond to further radiation she was transferred to the neurosurgical service.

Bilateral transections of the anterolateral pain tracts were made on 4/13/37 under local anaesthesia and the sensory level checked at the lower costal margin. The postoperative level was at the umbilicus with consequent complete relief of pain. Voluntary urination was re-established after a week. She was then able to get up without noticeable increase in leg weakness and appeared to be making a satisfactory convalescence until signs of uraemia appeared on the tenth day, with a rising level of nonprotein nitrogen and death in coma on the eighteenth day. Postmortem examination showed that she had destruction of the third lumbar vertebra with a psoas abscess, septicaemia, and a deep abscess beneath her superficially well-healed incision. Both ureters, as well as the lower vena cava, were occluded by tumour. Ever since this experience we have ordered routine intravenous pyelograms before undertaking surgery for relief of pain in all cases of malignant disease in the pelvis and lower abdomen. A photomicrograph of the spinal cord is reproduced in Figure 77B.

A feature of particular interest in this case was the examination of the spinal cord at the level of the anterolateral sections. In 1937 we were not carrying out incisions as far medial to the anterior root outflow as at present. Figure 77B shows that the tractotomy section, which was about 4 mm. deep, stopped at the line of the anterolateral sulcus. To have made the level rise above the tenth thoracic dermatome the incision would have had to be carried further ventrally and medially. Of equal interest is the fact that this incision appears to have been placed too far posteriorly, with the result that the ventral third of the pyramidal tract must have been injured. The fact that we had observed no striking weakness of the ipsilateral leg indicates that a considerable portion of the motor tract can be cut with little paralysis. This is in line with the results observed in Ebin's (1949) and Putnam and Herz's (1950) lateral tractotomies in Parkinson's disease. The evidence gained from this observation has led us to the conclusion that lasting paralysis is not generally due to the technical error of incising the cord posterior to the dentate ligament, but through the misfortune of injuring one of the

Alphonse E MGH U-227233	43	Osteochondrosarcoma R pelvis with pulmonary metastases. Paraplegia.	Lumbar and R sciatic distribution.	12/39	C5* T1*	L. R	T3 T8	Slight urinary infection (partial injury to bladder preoperatively).	Free of pain to death at 1 mos.
Arthur R. MGH U-270774 Dr. J. J. Michelsen	21	Osteogenic sarcoma L4 and L5 vertebrae	Back and L leg.	10/40	T2*	R.	T10	Transitory leg and bladder paresis which cleared.	Original pain relieved but he developed burning in L. foot and pain in R. leg as sarcoma spread to upper lumbar vertebrae. Died at 10 mos.
10. Joseph Z. MGH U-422456	33	Reticulum cell sarcoma R. ilium with R.L.Q. metastasis.	R. sacroiliac joint.	9/43	T2	L.	**	Multiple decubiti.	Relief to death at 7 mos.
11. Elizabeth C. MGH U-61120	46	Carcinoma of unknown origin with metastases to sacroiliac joint, para-aortic nodes, and L. ureter.	Sacroiliac tenderness and pain in L. pelvis and leg.	9/43	T3*	R.	T6	Transitory retention of urine.	Relief at discharge, but pain later extended to other leg. Died at 11 mos.
12. Charles D. MGH U-418466	71	Chondrosarcoma of sacrum.	L. buttock.	5/45	T3*	R.	T10	None.	Lasting relief, required no further narcotics to death at 6 mos.
13. Mary M. MGH U-387295 Dr. W. J. Mixter	49	Malignant tumour, type uncertain, of sacrum.	R. buttock with sciatic radiation.	1/46	T3*	L.	T10	None.	Effective relief, but developed milder pain in opposite leg. Died within 4 mos.
14. Everett D. MGH U-548611	55	Osteogenic sarcoma L. shoulder with pulmonary metastases.	Chest, L. shoulder, and arm.	10/46	Medulla*	R.	C2	Generalized convulsion on second day.	Operative death at 2 days.
15. Julius H. MGH U-559635	75	Sacral tumour removed 8 yrs. previously at another hospital. Recurrent chordoma with necrosis of sacrum, skin, and paralyzed bladder.	Sacrum and L. thigh.	1/47	T3* T2*	R. L.	T5 T9	No increase in sacral paralysis.	Relief to death at 5 mos.
16. Wallis C. MGH U-547682	18	Osteogenic sarcoma R. femur with metastases to T11 and T12 vertebrae with spinal compression.	Spine and R. pelvic amputation stump with added phantom sensation.	8/2/47 8/4/47	T2* T4* T2*	L. R. L.	L2 T7 T7	Paralysis L. leg, soon improved, then increased as tumour compressed cord.	Pain relieved. Died at 1 mo.

*Sensory level verified at operation.
**Inadequate information available in hospital records

Table XLIII

TUMOURS OF BONE (16 CASES)

Patient	Age	Tumour - Type and Location	Pain Reference	Date	Level of Cordotomy	Side	Sensory Level	Complications	Result
Spinothalamic Tractotomy									
1. William L. MGH #343776	29	R thigh amputated 11 mos. before for fibrosarcoma. Developed metastases R. femur, vertebrae, sacrum, humerus, and ribs.	Lumbosacral spine, pelvis, and R. thigh.	2/36	T2• T3•	R. L.	••	Hypotension and bronchopneumonia.	Pain relieved. Operativ death at 4 days.
2. Walter R. BM #22346 Dr. J. S. Hodgson	41	Osteochondrosarcoma R. thigh with metastases to T12 vertebra and paraplegia	Low back and legs unrelieved by decompressive laminectomy.	6/36	C7• T1•	R. L.	T9 T7	None. Previous paralysis unchanged.	Relief to death in 1937, bu paraesthesia developed which though less disagree able than former pain ulti mately required morphine
3. Abraham R. MGH U-1805 Dr. J. S Hodgson	54	Chondroma R. thoracic wall, ribs, and pleura.	Local pain upper chest not relieved by intercostal neurectomy. Occasional ulnar radiation.	1/37	C2•	L.	T2-T3	Transitory weakness L. leg.	Relief of former pain in chest, but pain in arm developed. Followed 5 mos.
4. Jennie C. MGH U-3846	24	Osteogenic sarcoma of ilium with paralysis L leg and bladder.	L. buttock and leg.	4/37	T2• T3•	R. L.	T9 T8	Previous weakness of R. leg and bladder were slightly increased.	Relief to death at 5 mos.
5. Emery W. MGH U-13871 Dr. J. S. Hodgson	38	Lymphoblastoma of sacroiliac joint with pelvic and abdominal metastases. Paraplegic and bedridden.	Both thighs.	7/37	C6• C7•	R. L.	T8 T8	Exsanguinating intestinal haemorrhage.	Complete relief, but died of disease on 3rd day, too early for evaluation.
6. Muriel P. MGH U-98266 Dr. J. S. Hodgson	26	Metastatic carcinoma lumbar spine, pelvis, and chest, of unknown origin.	Back, R. hip, and leg.	1/38	C7•	L.	T8	None.	Relief at discharge. Died within year.
Hazel P. MGH U-8549 Dr. J. J. Michelsen	38	Ewing's sarcoma of L femur with postamputation metastases to L. shoulder. R. femur, ischium, ribs, lungs, and skull.	R pelvis.	7/39	T2•	L.	T10	No postoperative complications, but gradually sank into coma.	Good relief of pain to death at 5 wks.

onse E I U-227233	43	Osteochondrosarcoma R pelvis with pulmonary metastases. Paraplegia.	Lumbar and R. sciatic distribution	12/39	C5* T1*	L. R.	T3 T8	Slight urinary infection (partial injury to bladder preoperatively).	Free of pain to death at 4 mos.
). Arthur R. MGH U-270774 Dr. J. J. Michelsen	24	Osteogenic sarcoma L4 and L5 vertebrae.	Back and L. leg	10/40	T2*	R.	T10	Transitory leg and bladder paresis which cleared.	Original pain relieved but he developed burning in L. foot and pain in R. leg as sarcoma spread to upper lumbar vertebrae. Died at 10 mos.
10. Joseph Z. MGH U-422456	33	Reticulum cell sarcoma R. ilium with R L.Q. metastasis.	R sacroiliac joint.	9/43	T2	L.	**	Multiple decubiti.	Relief to death at 7 mos.
11. Elizabeth C. MGH U-61120	46	Carcinoma of unknown origin with metastases to sacroiliac joint, para-aortic nodes, and L. ureter	Sacroiliac tenderness and pain in L pelvis and leg.	9/43	T3*	R.	T6	Transitory retention of urine.	Relief at discharge, but pain later extended to other leg. Died at 11 mos.
12. Charles D. MGH U-418466	71	Chondrosarcoma of sacrum.	L. buttock.	5/45	T3*	R.	T10	None.	Lasting relief, required no further narcotics to death at 6 mos.
13. Mary M. MGH U-387295 Dr. W. J. Mixter	49	Malignant tumour, type uncertain, of sacrum	R. buttock with sciatic radiation.	1/46	T3*	L.	T10	None.	Effective relief, but developed milder pain in opposite leg. Died within 4 mos.
14. Everett D. MGH U-548611	55	Osteogenic sarcoma L. shoulder with pulmonary metastases.	Chest, L. shoulder, and arm.	10/46	Medulla*	R.	C2	Generalized convulsion on second day.	Operative death at 2 days.
5. Julius H. MGH U-559635	75	Sacral tumour removed 8 yrs. previously at another hospital. Recurrent chordoma with necrosis of sacrum, skin, and paralyzed bladder.	Sacrum and L. thigh.	1/47	T3* T2*	R. L.	T5 T9	No increase in sacral paralysis.	Relief to death at 5 mos.
3. Wallis C. MGH U-547682	18	Osteogenic sarcoma R. femur with metastases to T11 and T12 vertebrae with spinal compression.	Spine and R. pelvic amputation stump with added phantom sensation.	8/2/47 8/4/47	T2* T4* T2*	L. R. L.	L2 T7 T7	Paralysis L. leg, soon improved, then increased as tumour compressed cord.	Pain relieved. Died at 1 mo.

Sensory level verified at operation.
Inadequate information available in hospital records.

TABLE XLIII

TUMOURS OF BONE (16 CASES)

Patient	Age	Tumour - Type and Location	Pain Reference	Date	Level of Cordotomy	Side	Sensory Level	Compl[illegible]	Result
Spinothalamic Tractotomy									
1. William L. MGH #343776	29	R. thigh amputated 11 mos. before for fibrosarcoma. Developed metastases R. femur, vertebrae, sacrum, humerus, and ribs.	Lumbosacral spine, pelvis, and R. thigh	2/36	T2* T3*	R. L.	**	Hypotension and bronchopneumonia.	Pain relieved. Operative death at 4 days.
2. Walter R BM #22346 Dr. J. S. Hodgson	41	Osteochondrosarcoma R. thigh with metastases to T12 vertebra and paraplegia.	Low back and legs unrelieved by decompressive laminectomy.	6/36	C7* T1*	R. L.	T9 T7	None. Previous paralysis unchanged.	Relief to death in 1937, but paraesthesia developed, which though less disagreeable than former pain ultimately required morphine.
3. Abraham R. MGH U-1805 Dr. J. S. Hodgson	54	Chondroma R. thoracic wall, ribs, and pleura.	Local pain upper chest not relieved by intercostal neurectomy. Occasional ulnar radiation.	1/37	C2*	L.	T2-T3	Transitory weakness L. leg.	Relief of former pain in chest, but pain in arm developed. Followed 5 mos.
4. Jennie C. MGH U-3846	24	Osteogenic sarcoma of ilium with paralysis L. leg and bladder.	L. buttock and leg.	4/37	T2* T3*	R. L.	T9 T8	Previous weakness of R. leg and bladder were slightly increased.	Relief to death at 5 mos.
5. Emery W. MGH U-13871 Dr. J. S. Hodgson	38	Lymphoblastoma of sacroiliac joint with pelvic and abdominal metastases. Paraplegic and bedridden.	Both thighs.	7/37	C6* C7*	R. L.	T8 T8	Exsanguinating intestinal haemorrhage.	Complete relief, but died of disease on 3rd day, too early for evaluation.
6. Muriel P. MGH U-98266 Dr. J. S. Hodgson	26	Metastatic carcinoma lumbar spine, pelvis, and chest, of unknown origin.	Back, R. hip, and leg.	1/38	C7*	L.	T8	None.	Relief at discharge. Died within year.
7. Hazel P. MGH U-8549 Dr. J. J. Michelsen	38	Ewing's sarcoma of L. femur with postamputation metastases to L. shoulder. R femur, ischium, ribs, lungs, and skull.	R pelvis.	7/39	T2*	L.	T10	No postoperative complications, but gradually sank into coma.	Good relief of pain to death at 5 wks.

Alphonse E. MGH U-227233	43	Osteochondrosarcoma R. pelvis with pulmonary metastases. Paraplegia.	Lumbar and R sciatic distribution	12/39	C5* T1*	L. R.	T3 T8	Slight urinary infection (partial injury to bladder preoperatively).	Free of pain to death at 4 mos.
Arthur R. MGH U-270774 Dr. J. J. Michelsen	24	Osteogenic sarcoma L4 and L5 vertebrae	Back and L leg.	10/40	T2*	R.	T10	Transitory leg and bladder paresis which cleared.	Original pain relieved but he developed burning in L. foot and pain in R. leg as sarcoma spread to upper lumbar vertebrae. Died at 10 mos.
10. Joseph Z. MGH U-422456	33	Reticulum cell sarcoma R. ilium with R L.Q. metastasis.	R. sacroiliac joint.	9/43	T2	L.	**	Multiple decubiti.	Relief to death at 7 mos.
11. Elizabeth C. MGH U-61120	46	Carcinoma of unknown origin with metastases to sacroiliac joint, para-aortic nodes, and L. ureter.	Sacroiliac tenderness and pain in L. pelvis and leg.	9/43	T3*	R.	T6	Transitory retention of urine.	Relief at discharge, but pain later extended to other leg. Died at 11 mos.
12. Charles D. MGH U-418466	71	Chondrosarcoma of sacrum.	L. buttock.	5/45	T3*	R.	T10	None.	Lasting relief, required no further narcotics to death at 6 mos.
13. Mary M. MGH U-387295 Dr. W. J. Mixter	49	Malignant tumour, type uncertain, of sacrum	R. buttock with sciatic radiation.	1/46	T3*	L.	T10	None.	Effective relief, but developed milder pain in opposite leg. Died within 4 mos.
14. Everett D. MGH U-548611	55	Osteogenic sarcoma L. shoulder with pulmonary metastases.	Chest, L. shoulder, and arm.	10/46	Medulla*	R.	C2	Generalized convulsion on second day.	Operative death at 2 days.
15. Julius H. MGH U-559635	75	Sacral tumour removed 8 yrs. previously at another hospital. Recurrent chordoma with necrosis of sacrum, skin, and paralyzed bladder.	Sacrum and L. thigh.	1/47	T3* T2*	R. L.	T5 T9	No increase in sacral paralysis.	Relief to death at 5 mos.
16. Wallis C. MGH U-547682	18	Osteogenic sarcoma R. femur with metastases to T11 and T12 vertebrae with spinal compression.	Spine and R. pelvic amputation stump with added phantom sensation.	8/2/47 8/4/47	T2* T4* T2*	L. R. L.	L2 T7 T7	Paralysis L. leg, soon improved, then increased as tumour compressed cord.	Pain relieved. Died at 1 mo.

*Sensory level verified at operation.
**Inadequate information available in hospital records.

comas, and lymphomas. Pain in these conditions is usually due to direct invasion of sensory endings in fascia and periosteum, or from metastasis to the region of the paravertebral nerve plexuses and vertebrae. This type of pain, if not situated too high, usually responds well to cordotomy, as can be seen from a study of Table XLIV. There was complete relief in seven out of nine patients, with failure in two (Cases 5 and 6) due to incomplete levels of analgesia. In neither of these patients was it possible to test the sensory level at the time of operation, owing to poor cooperation of the patient on awakening from Pentothal and nitrous oxide anaesthesia. There were no serious postoperative complications except in Patient 5.

It was possible to re-examine Patient 8 three years after her unilateral tractotomy for a recurrent malignant melanoma in the right groin and pelvis, and the results in this case were so impressive that her history is recorded in some detail:

Patient 8, Margaret L., MGH U-509342, 31, had had an excision of a broken-down malignant melanoma from her right ankle in December, 1945, followed by a radical groin dissection. In the following May she was readmitted with an extensive inguinal recurrence, and severe burning pain in this area which radiated to the buttock. A second block resection of the tumour in the groin was carried out on the surgical service and on 5/20/46 (11 days later) a left anterolateral cordotomy at T1. Three progressively deeper sections were necessary to establish a satisfactory level, as analgesia after the first incision, although reaching the posterior axillary fold, was incomplete over the buttock. At this point she said that her original pain was still present, so that the operation would certainly have failed had not the surgeon spent the time necessary to awaken the patient and test the sensory level.

Postoperative recovery was uneventful except for insignificant weakness of the left leg and incisional discomfort, which radiated over the course of the ulnar nerve. Both disappeared in a fortnight. The left leg, as is sometimes observed, was distinctly warmer than the right. Sexual sensation was unaffected by the operation. She became pregnant and had to be delivered by Caesarean section because of a large pelvic mass. The latter disappeared after treatment with radiation. At three years she remained free of pain, but subjectively unaware of the left-sided analgesia, which extended to the nipple line. The patient looked well and continued to live a normal life, taking care of her home and family.

B. COMMENT ON OVER-ALL RESULTS

Results following spinothalamic tract sections performed on these 129 patients with painful malignant disease have been generally satisfactory. To summarize, 104 (81 per cent) had effective early relief of pain for which

Table XLIV

TUMOURS OF SKIN, MUSCLE, AND FASCIA (9 CASES)

Patient	Age	Tumour - Type and Location	Pain Reference	Date	Level of Cordotomy	Side	Sensory Level	Complications	Result
Spinothalamic Tractotomy									
1. Joseph C. MGH U-1806 Dr. J. S. Hodgson	40	Reticulum cell sarcoma abdomen and pelvis with metastases to cervical nodes and L2 vertebra.	L. lumbar region and leg.	1/37	C7*	R.	T5	None.	Relief. Died at 2 mos.
2. Barney S. MGH U-6542	60	Reticulum cell sarcoma L. axilla and chest.	Local.	2/37	C5*	R.	Hypalgesia T1	Increase in reflexes R. arm and leg.	Temporary relief.
				4/37	C6*	R.	Analgesia C8	None.	Relief at discharge. Followed 3 mos.
3. Alice D. MGH U-122963 Dr. J. J. Michelsen	60	Melanosarcoma L. groin with metastases to os calcis and L3 vertebra	L groin and leg.	1/38	T1* T2*	R. L.	**	None.	Relief at discharge. No follow-up.
4. Lionel B. MGH U-306631	28	Recurrent melanosarcoma of R. thigh with metastases to groin.	Low back and R. thigh.	6/41	T1*	L.	T8	None.	Relief at discharge. Died at 5 mos.
5. Thora T. MGH U-3466 Dr. W. J. Mixter	49	Recurrent leiomyosarcoma after hysterectomy with metastasis to L4 vertebra.	Low back and legs, not relieved by decompressive laminectomy.	9/41	T2 T3	L. R.	Analgesia T8 Hypalgesia T8	Stormy recovery due to pulmonary complications, urinary sepsis, and advanced malignant disease.	Relief on R. Failure on L., but improved by intrathecal alcohol injections. Died at 7 mos.
6. Rose M. MGH U-308703 Dr. J. J. Michelsen	56	Myxosarcoma of R. thigh with metastases to T12 vertebra.	R. lower chest and abdomen.	11/41	C2	L.	Hypalgesia T3, Analgesia L1	None.	Failure on account of inadequate level. Died at 58 mos.
7. Walter C. MGH U-358346 Dr. J. J. Michelsen	55	Lymphoma of L. thoracic wall.	L. chest, shoulder, and arm.	1/43	C3	R.	C6	None.	Relieved to death in about 1 yr.
8. Margaret L. MGH U-509342	31	Recurrent melanosarcoma of R. thigh, groin, sacrum, and pelvis.	R. groin and leg.	5/46	T1*	L.	T5	None.	Pain free while followed for 3 yrs.
9. Ruth P. MGH U-552391	43	Leiomyosarcoma involving peritoneum, sigmoid, and small intestine.	Lower abdomen and pelvis with leg radiation.	5/47	T2* T1*	L. R.	T7 T9	Transitory leg weakness, which rapidly cleared. Bladder recovered in 12 days.	Relief. Died at 7 wks.

*Sensory level verified at operation. In some cases this could not be satisfactorily carried out. This was true of Patients 5 and 6, who were unable to cooperate, and operation failed to establish a satisfactory level of analgesia.
**Inadequate information available in hospital records.

the operation was undertaken, while 16 were not benefited and nine died too soon to evaluate the effectiveness of the operation. Three of these deaths were due to complications of malignant disease and six must be attributed to operation on poor-risk patients.

In 28 there was residual pain after a unilateral tractotomy, the symptoms being referred to the side with remaining intact sensation. In 11 of these the residual pain was relieved by a second cordotomy on the opposite side. The majority of the others were grateful for their partial relief. In many the pain was not severe enough to warrant further sensory denervation and in some it only reached such intensity in the final weeks of life when recourse to narcotics was a perfectly justifiable solution. There was only a single instance (Patient 32, Table XLII) where pain continued despite an apparently effective analgesia. In this woman burning perianal pain continued to be very troublesome. We have seen this type of pain continue despite adequate analgesia on several other occasions and are unable to explain it.

We attribute the satisfactory level of analgesia in such a large proportion of cases to the policy of making an unusually radical transection of the anterolateral quadrant of the cord and then testing the sensory level on the operating table. The importance of this cannot be over-emphasized, and its neglect in other clinics accounts for many unsatisfactory reports. It was possible to establish the presence of a satisfactory level on the operating table in three-quarters of these patients,* in many of whom a second or even a third deeper and more anterior incision of the cord was required in order to bring the level up to the required dermatome. In one instance (Patient 8, Table XLIV) an area of intact sensation persisted in the buttock despite otherwise complete analgesia to T5. It required two further incisions to interrupt these fibres and remove residual sensation from the pelvic metastasis.

An aspect of these statistics open to criticism is the relatively short period of follow-up in the majority. Once they are sent home or to another institution for terminal care individuals with advanced malignant disease are not easily transported back for late studies. Many survived for only a short time and it was difficult to get intelligent descriptions of the end result from their families. Nevertheless in 61 it was possible to obtain follow-up data for periods ranging from two months up to three years after cordotomy. Further troublesome pain developed within the initial analgesic area in 10 of these. Therefore we feel reasonably sure that there have been relatively few failures to relieve the original pain over the span of life in

*To-day, supplementing local infiltration with short-acting general anaesthetics and light basic Pentothal (see p. 209), it is possible to expose, rotate, and incise the cord with the patient asleep. Then, after withdrawal of nitrous oxide or Trilene, about 90 per cent of patients are soon sufficiently cooperative for sensory testing

the others. In another nine the later appearance of high metastases again caused pain of a different type, which could only have been relieved by some form of leucotomy.

Thorough and prolonged observations made on patients after anterolateral cordotomy are analyzed in Chapter IX. This reviews the incidence of such complications as incisional pain, retention of urine, weakness of a leg from injury to the pyramidal tract, etc. In this group of patients with malignant disease the incidence of these complications need not be summarized separately, as this has been reported for the individual groups above and is included in the tables. It is remarkable that the incidence of serious complications has been so low, considering the fact that many of these patients already had involvement of the motor innervation to their extremities and bladder, and that mechanical difficulties with urination were occasionally present as well.

In retrospect the survival period of only a month or two in a considerable number of these patients (four out of six in the group with vesical carcinoma) may have been too short to have justified cordotomy. This raises the very pertinent question as to whether the surgeons on our service have not been over-zealous in recommending such a radical procedure, when the patient might well have been treated over such a short survival period by medication alone. We think not. The pain at times reaches an intensity at which massive doses of potent analgesic medication fail to control it, and we have operated with gratifying results in several such patients who were able to pass their remaining few weeks of life in relative comfort. On the other hand, as long as a patient can be kept comfortable by medication it has been our working rule not to intervene when he appears doomed to die within two months. We know of no method of predicting this period with accuracy and have, for better or worse, relied on the opinion of the surgical staff and tumour clinic. We have, however, rarely experienced any regrets on this score, as one has only to witness the changes that take place in the mental outlook of the sufferers to be convinced that occasional complications such as incisional pain, retention of urine, or weakness of a leg, all of which are usually transitory, are a price well worth paying for release from constant nagging pain.

One final point that deserves consideration is the comparative value of frontal leucotomy for the relief of suffering in cancer. Nine patients who have been submitted to this procedure are listed in the tables of Chapter X and further discussed in this chapter. Aside from the cephalalgias, it is only when pain has spread to very high levels in the neck or to both sides of the upper thorax that some form of leucotomy can be advocated in preference to specific interruption of pain pathways. This is particularly true in carcinoma of the breast, where there may be high pulmonary or widespread

the operation was undertaken, while 16 were not benefited and nine died too soon to evaluate the effectiveness of the operation. Three of these deaths were due to complications of malignant disease and six must be attributed to operation on poor-risk patients.

In 28 there was residual pain after a unilateral tractotomy, the symptoms being referred to the side with remaining intact sensation. In 11 of these the residual pain was relieved by a second cordotomy on the opposite side. The majority of the others were grateful for their partial relief. In many the pain was not severe enough to warrant further sensory denervation and in some it only reached such intensity in the final weeks of life when recourse to narcotics was a perfectly justifiable solution. There was only a single instance (Patient 32, Table XLII) where pain continued despite an apparently effective analgesia. In this woman burning perianal pain continued to be very troublesome. We have seen this type of pain continue despite adequate analgesia on several other occasions and are unable to explain it.

We attribute the satisfactory level of analgesia in such a large proportion of cases to the policy of making an unusually radical transection of the anterolateral quadrant of the cord and then testing the sensory level on the operating table. The importance of this cannot be over-emphasized, and its neglect in other clinics accounts for many unsatisfactory reports. It was possible to establish the presence of a satisfactory level on the operating table in three-quarters of these patients,* in many of whom a second or even a third deeper and more anterior incision of the cord was required in order to bring the level up to the required dermatome. In one instance (Patient 8, Table XLIV) an area of intact sensation persisted in the buttock despite otherwise complete analgesia to T5. It required two further incisions to interrupt these fibres and remove residual sensation from the pelvic metastasis.

An aspect of these statistics open to criticism is the relatively short period of follow-up in the majority. Once they are sent home or to another institution for terminal care individuals with advanced malignant disease are not easily transported back for late studies. Many survived for only a short time and it was difficult to get intelligent descriptions of the end result from their families. Nevertheless in 61 it was possible to obtain follow-up data for periods ranging from two months up to three years after cordotomy. Further troublesome pain developed within the initial analgesic area in 10 of these. Therefore we feel reasonably sure that there have been relatively few failures to relieve the original pain over the span of life in

*To-day, supplementing local infiltration with short-acting general anaesthetics and light basic Pentothal (see p. 209), it is possible to expose, rotate, and incise the cord with the patient asleep. Then, after withdrawal of nitrous oxide or Trilene, about 90 per cent of patients are soon sufficiently cooperative for sensory testing

the others. In another nine the later appearance of high metastases again caused pain of a different type, which could only have been relieved by some form of leucotomy.

Thorough and prolonged observations made on patients after antero-lateral cordotomy are analyzed in Chapter IX. This reviews the incidence of such complications as incisional pain, retention of urine, weakness of a leg from injury to the pyramidal tract, etc. In this group of patients with malignant disease the incidence of these complications need not be summarized separately, as this has been reported for the individual groups above and is included in the tables. It is remarkable that the incidence of serious complications has been so low, considering the fact that many of these patients already had involvement of the motor innervation to their extremities and bladder, and that mechanical difficulties with urination were occasionally present as well.

In retrospect the survival period of only a month or two in a considerable number of these patients (four out of six in the group with vesical carcinoma) may have been too short to have justified cordotomy. This raises the very pertinent question as to whether the surgeons on our service have not been over-zealous in recommending such a radical procedure, when the patient might well have been treated over such a short survival period by medication alone. We think not. The pain at times reaches an intensity at which massive doses of potent analgesic medication fail to control it, and we have operated with gratifying results in several such patients who were able to pass their remaining few weeks of life in relative comfort. On the other hand, as long as a patient can be kept comfortable by medication it has been our working rule not to intervene when he appears doomed to die within two months. We know of no method of predicting this period with accuracy and have, for better or worse, relied on the opinion of the surgical staff and tumour clinic. We have, however, rarely experienced any regrets on this score, as one has only to witness the changes that take place in the mental outlook of the sufferers to be convinced that occasional complications such as incisional pain, retention of urine, or weakness of a leg, all of which are usually transitory, are a price well worth paying for release from constant nagging pain.

One final point that deserves consideration is the comparative value of frontal leucotomy for the relief of suffering in cancer. Nine patients who have been submitted to this procedure are listed in the tables of Chapter X and further discussed in this chapter. Aside from the cephalalgias, it is only when pain has spread to very high levels in the neck or to both sides of the upper thorax that some form of leucotomy can be advocated in preference to specific interruption of pain pathways. This is particularly true in carcinoma of the breast, where there may be high pulmonary or widespread

bony metastases, and in certain tumours in the neck and upper portion of the chest. As emphasized in Chapter IX, *leucotomy for relief of pain may cause such severe psychological deterioration that its use is justified only in the exceptional cases where cordotomy or rhizotomy is known to be ineffective, or in those hopeless situations where an advanced morphine addiction or fear of imminent death from haemorrhage or strangulation can be controlled in no other way. In all other circumstances it is our opinion that posterior rhizotomy or spinothalamic tractotomy are still the operations of choice. We consider the risks of damage to the bladder and pyramidal tract of minor consequence in comparison with the psychological deterioration of the patient, which so often follows any form of leucotomy in current use when performed on the nonpsychotic individual.*

CHAPTER XIX

PAIN IN DISEASE OF THE THORACIC VISCERA

TWENTY-FIVE YEARS AGO, when the senior author started to study the neural afferent pathways in visceral disease, physicians were quite unaware of the fact that these deeper structures had direct nervous connections with the thalamus and sensory cortex. This misconception arose from observations made during early operations under local anaesthesia. As Lennander (1901) first pointed out, the viscera are insensitive to ordinary stimuli such as cutting, crushing, and burning. They are, however, sensitive to such physiological stimuli as distension (Hurst, 1911), anoxia (Sutton and Lueth, 1930), and acid metabolites such as lactic acid (Moore and Singleton, 1933).

Anatomical investigation has disclosed that afferent nerves to the viscera are less numerous than those to the surface of the body, but their receptor endings for pain differ in no other important respect. These fibres in their central course run in the mixed visceral nerves, intermingled with the sympathetic motor axones. They lie in close contact with the visceral arteries and are concentrated in the hypogastric, splanchnic, and cardiac plexuses. After passing through these important sensory-motor distributing points and the paravertebral ganglia, the viscerosensory axones continue without synaptic interruption via the rami communicantes to enter the spinal nerves. Evidence cited on pp. 85-86 indicates that grey as well as white rami may be concerned. Here they split off from the sympathetic preganglionic fibres to enter posterior spinal roots. Their trophic cells lie in the sensory root ganglia and send central processes to the posterior horn of grey matter in the spinal cord. At this point synaptic connections are established with the upper sensory neurone cells. From here upwards the visceral pain pathway in the cord differs in no way from that which carries somatic pain, decussating in the anterior commissure and ascending in the contralateral quadrant of the spinal cord.

Differences in perception of visceral and somatic pain, the higher threshold and cruder perception of the former, can be explained on the basis of the smaller supply of sensory fibres to the viscera. Even the phenomenon of reference of visceral pain is not fundamentally different from that of other deep structures supplied by somatic nerves, such as the diaphragm, skeletal muscles, joints, and ligaments.

bony metastases, and in certain tumours in the neck and upper portion of the chest. As emphasized in Chapter IX, *leucotomy for relief of pain may cause such severe psychological deterioration that its use is justified only in the exceptional cases where cordotomy or rhizotomy is known to be ineffective, or in those hopeless situations where an advanced morphine addiction or fear of imminent death from haemorrhage or strangulation can be controlled in no other way. In all other circumstances it is our opinion that posterior rhizotomy or spinothalamic tractotomy are still the operations of choice. We consider the risks of damage to the bladder and pyramidal tract of minor consequence in comparison with the psychological deterioration of the patient, which so often follows any form of leucotomy in current use when performed on the nonpsychotic individual.*

These observations are in line with Lennander's (1901) findings that the viscera are insensitive to cutting, crushing, and even burning. The error in their interpretation lay in the failure of these experimenters to utilize a proper physiological stimulus. In the case of hollow viscera, Hurst (1911) has shown that distension is the physiological stimulus, while for the heart the more recent work of Sutton and Lueth (1930) and others (Blumgart, Schlesinger, and Davis, 1940) points to myocardial anoxia and abnormal products of muscular fatigue as the cause of angina pectoris. Knowledge of Sutton and Lueth's method of inducing coronary pain in dogs by temporary occlusion of a coronary artery permitted White, Garrey, and Atkins (1933) to carry out the crucial experiments required to establish the pathways of cardiac pain in man.* This work showed that myocardial ischaemia was still productive of pain after bilateral cervical sympathectomy carried down through the stellate ganglia (Fig. 126). On the other hand, no pain could be induced, even by prolonged coronary occlusion, after resection of both stellates and the upper four pairs of thoracic ganglia or division of the upper five pairs of thoracic posterior spinal roots. This experiment gave the necessary physiological proof of the presence of direct thoracic cardiac connections. Whether the anatomical arrangement was the same in man as in the dog still remained to be verified. Results of surgical de-afferentiation of the heart in man have long since proved this to be the case.

When cervical sympathectomy was first attempted by Jonnesco (1920) for relief of persistent pain in angina pectoris, as first proposed by François-Franck (1899), only the three cervical cardiac nerves were known. Many failures resulted until the anatomical discovery of the *accessory thoracic* cardiac nerves by Braeucker (1927), Jonnesco and Enarchesco (1927), Kuntz and Morehouse (1930), and the physiological proof by White, Garrey, and Atkins (1933) that they transmit sensation of pain from the heart.

Study of Figure 127 will serve to illustrate the most practicable methods for achieving a complete interruption of pain-conducting pathways from the heart. It is generally recognized that sensory axones from the cardiac plexuses reach the chain of paravertebral ganglia over the middle and inferior cardiac nerves, also over the upper thoracic rami. Evidence has been

*In using Sutton and Lueth's preparation, a silk ligature was passed beneath the upper portion of the descending branch of the *left* coronary artery and then brought out through the chest wall *in a glass tube*. These animals recovered rapidly from ether anaesthesia. They were then ready for testing, the type of cardiac denervation to be evaluated having been carried out several weeks previously. When cardiac pain fibres remained uncut, traction on the ligature for a period of only a *few seconds invariably* produced a change in the rate and depth of respiration, soon followed by unmistakable evidence of discomfort. The stimulus was always interrupted before any real suffering was produced.

The facts summarized above and set forth in greater detail in Chapters II and III explain why pain of purely visceral origin can be relieved by resection of terminal periarterial plexuses (e.g., stripping the renal vessels and pericoronary neurectomy), interruption of splanchnic trunks or appropriate paravertebral ganglia, division of the corresponding posterior roots, and by spinothalamic tractotomy.

A striking fact which has been established in recent years is that surgical relief of visceral pain can be accomplished more simply, with less mutilation, and with greater certainty of success than in many common somatic syndromes such as the pain of phantom limb, herpes zoster, and other puzzling neuralgias. The only necessary qualification of this statement is that the disease must be localized in the viscus. Pain of idiopathic dysmenorrhea, for example, can be effectively relieved by resection of the superior hypogastric plexus. On the contrary, this is not true of uterine carcinoma with radiation to the legs because, by the time this pain develops, the malignant cells have spread out through lymphatic channels in the broad ligaments and invaded the lumbosacral plexus. The justification for the above statements, which will appear radical to many surgeons, is given in their practical application set forth in the two chapters which follow.

A. HEART*

1. Anatomy and Physiology of Cardiac Pain

The heart, like the abdominal viscera, had first been thought to be devoid of pain sensation. It is of interest to find that early observations on this subject date back to William Harvey (quoted by Goltz, 1863). His subject was the young son of Count Montgomery, a friend of King Charles I, who had received a severe wound in the chest as a child. Although the thoracic cavity had been opened widely, the accident had not ended in death but in healing with the heart exposed. On taking off a sort of cardiac cuirass, Harvey saw the beating heart. Touching, pricking, or pinching the heart caused not the slightest sensation. A similar modern observation has been put on record by Alexander, Macleod, and Barker (1929), who studied a patient with open drainage of the pericardium which exposed the lower portions of the ventricles and the diaphragm. They also found the visceral pericardium over the ventricles to be insensitive to touch. Heat, cold, and vibrations were not perceived at all, and electrical stimulation evoked sensation only when it produced extrasystoles.

*Much of the text in this section, as well as the tables, case histories, and illustrations, are reproduced from an article by White and Bland (1948) which appeared in *Medicine*. We wish to thank the editor for his kindness in permitting its republication in a reduced and slightly modified form. The reader who is particularly interested in this subject should refer to the unabridged article in the journal

These observations are in line with Lennander's (1901) findings that the viscera are insensitive to cutting, crushing, and even burning. The error in their interpretation lay in the failure of these experimenters to utilize a proper physiological stimulus. In the case of hollow viscera, Hurst (1911) has shown that distension is the physiological stimulus, while for the heart the more recent work of Sutton and Lueth (1930) and others (Blumgart, Schlesinger, and Davis, 1940) points to myocardial anoxia and abnormal products of muscular fatigue as the cause of angina pectoris. Knowledge of Sutton and Lueth's method of inducing coronary pain in dogs by temporary occlusion of a coronary artery permitted White, Garrey, and Atkins (1933) to carry out the crucial experiments required to establish the pathways of cardiac pain in man.* This work showed that myocardial ischaemia was still productive of pain after bilateral cervical sympathectomy carried down through the stellate ganglia (Fig. 126). On the other hand, no pain could be induced, even by prolonged coronary occlusion, after resection of both stellates and the upper four pairs of thoracic ganglia or division of the upper five pairs of thoracic posterior spinal roots. This experiment gave the necessary physiological proof of the presence of direct thoracic cardiac connections. Whether the anatomical arrangement was the same in man as in the dog still remained to be verified. Results of surgical de-afferentiation of the heart in man have long since proved this to be the case.

When cervical sympathectomy was first attempted by Jonnesco (1920) for relief of persistent pain in angina pectoris, as first proposed by François-Franck (1899), only the three cervical cardiac nerves were known. Many failures resulted until the anatomical discovery of the accessory thoracic cardiac nerves by Braeucker (1927), Jonnesco and Enarchesco (1927), Kuntz and Morehouse (1930), and the physiological proof by White, Garrey, and Atkins (1933) that they transmit sensation of pain from the heart.

Study of Figure 127 will serve to illustrate the most practicable methods for achieving a complete interruption of pain-conducting pathways from the heart. It is generally recognized that sensory axones from the cardiac plexuses reach the chain of paravertebral ganglia over the middle and inferior cardiac nerves, also over the upper thoracic rami. Evidence has been

*In using Sutton and Lueth's preparation, a silk ligature was passed beneath the upper portion of the descending branch of the left coronary artery and then brought out through the chest wall in a glass tube. These animals recovered rapidly from ether anaesthesia. They were then ready for testing, the type of cardiac denervation to be evaluated having been carried out several weeks previously. When cardiac pain fibres remained uncut, traction on the ligature for a period of only a few seconds invariably produced a change in the rate and depth of respiration, soon followed by unmistakable evidence of discomfort. The stimulus was always interrupted before any real suffering was produced.

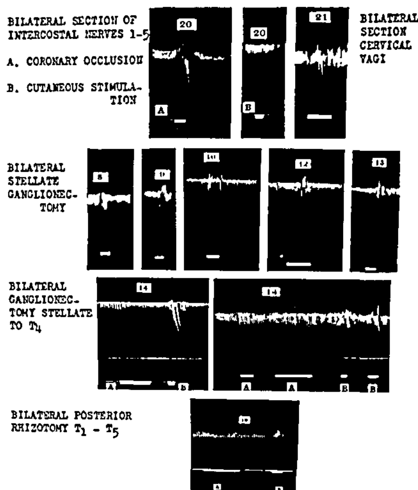


Fig. 126 Experimental cardiac pain in dogs

The upper line in each kymographic tracing represents respiratory movements, which increased in depth whenever the animals experienced any discomfort. The lower unmarked signals and those marked "A" indicate periods during which the descending branch of the left coronary artery was occluded At signals marked "B" the skin was pinched. Animal No. 20 did not feel cutaneous stimulation over the thoracic wall, but increase in respiration was clear-cut.

From White and Bland: *Medicine*, 1948 Courtesy, The Williams and Wilkins Co, Baltimore

presented by Davis and Pollock (1932) from animal experiments that the superior cardiac nerve and upper cervical ganglion from which it arises contain no afferent connections with the spinal cord. Our evidence, from stimulating the superior cervical sympathetic ganglion in man (p. 84), forces us to conclude that, at least in some individuals, there may be true afferent fibres in the upper portion of the cervical sympathetic trunk. This is a possible anatomical explanation for the early reports (Coffey and Brown, 1923) of occasional successful results of superior cervical ganglionectomy in the relief of angina pectoris. It may be pointed out, how-

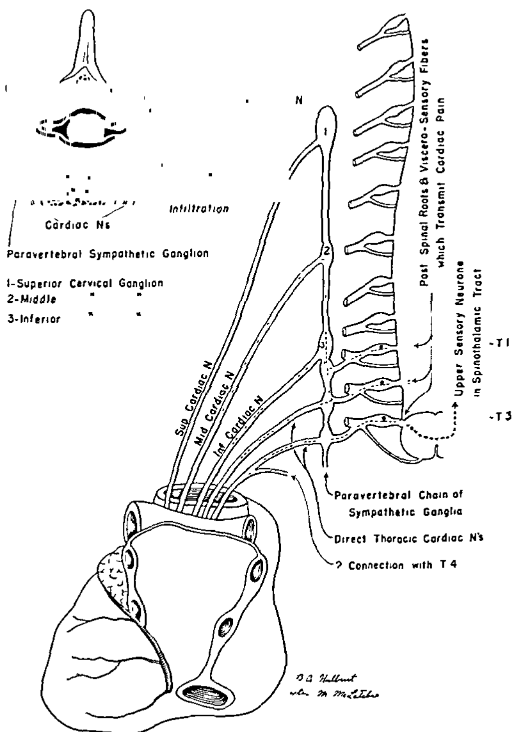


Fig. 127. The cardiosensory pathways.
A similar arrangement exists on the opposite side
From White: *Research Publ. A Nerv. & Ment Dis.*, 1943 Courtesy, The Williams and Wilkins Co, Baltimore.

of the upper four thoracic sensory roots has proved to be an equally effective operation (Table XLV).

The only area to which we are aware that pain can be referred after these crucial lines of communication have been interrupted is the lower jaw and neck. This unusual radiation, which is not often severe enough to require further surgical intervention, has been seen in a small proportion of patients and in one still persisted after resection of the superior cervical ganglion and the superficial cervical plexus. Lindgren and Olivecrona (1947) have also observed this and found that the pain disappeared after injection of the mandibular nerve. It is probable that its afferent pathway from the heart to the brain stem is over the vagi, and that some peripheral reflex mechanism gives rise to local pain in the trigeminal area. The vagi fortunately play no other role in the conduction of cardiac pain, although they may transmit the dull sense of oppression felt in the suprasternal notch after complete sympathetic denervation of the heart and thereby preserve an adequate warning signal of myocardial ischaemia.

Distribution of the cardiac sensory nerves is entirely unilateral, so that after their effective interruption on one side pain may still be present on the other, although this sensation stops at the midline. After bilateral interruption all sensation of pain disappears, but the patient will still appreciate when he is overtaxing his heart by a sense of painless oppression or constriction, usually located in the suprasternal notch, or by dyspnoea, palpitation, and other sensations related to abnormal action of the heart. We have seen this essential danger signal lost temporarily in only a single instance. Here, following an unusually widespread paravertebral block with procaine, the patient, after taking an over-vigorous exercise tolerance test, developed an attack of intense but painless dyspnoea. In this instance it is reasonable to assume that the procaine had infiltrated the vagal as well as the sympathetic fibres to the heart. Sir James Mackenzie's (1924) fear that discovery of a successful surgical method of relieving the pain of angina pectoris would leave the patient without an effective warning against overexertion has fortunately proved to be unfounded.

Anatomical considerations, as pointed out in the preceding section, favour surgical intervention either on the upper thoracic paravertebral ganglia or on the corresponding posterior spinal roots, which carry the pain-transmitting fibres from the heart. These areas constitute the bottleneck through which all pain-conducting axones from the widely ramifying peripheral plexuses are funnelled before entering the spinal cord. When operating in this region the surgeon encounters structures which are easy to identify and free from unusual anatomical variations. Sensory regeneration cannot take place after rhizotomy, and after resection of an extensive segment of the upper thoracic ganglia it is not likely to occur.

The heart being a midline organ, pain is often referred to the retrosternal area and to one or both arms. Usually reference is primarily to the left and a unilateral denervation on this side will give sufficient relief so that the patient can get along on routine medical treatment. Embryological and clinical evidence, recently cited by Wyburn-Mason (1950), suggests that the left chambers of the heart, pulmonary veins, and interatrial septum develop and receive their nerve supply from the left side. As the right auricle and ventricle develop on the opposite side, disease involving these structures is likely to be referred primarily to the right. A case of dextrocardia with accompanying angina pectoris is reported in which the pain was right-sided.

2. Surgical Methods for Sensory Denervation of the Heart

The technical methods of cardiac de-afferentiation are described in Chapter XI. At this point it is necessary only to consider the individual merits of chemical blocking of the cardiosensory fibres as they traverse the upper three or four thoracic sympathetic ganglia, as compared with surgical removal of these ganglia or division of the corresponding posterior spinal roots.

We have not discussed a number of alternative surgical methods for the following reasons. Fauteux's (1946) proposal of pericoronary neurectomy is perhaps the most difficult and uncertain method of interrupting the cardiosensory nerves. All operations which involve direct exposure of the heart are certain to carry an excessive risk of mortality. This amounted to 37.8 per cent in Beck's (cited by Feil, 1943) early attempts at revascularization of the heart by creating adhesions between two layers of the pericardium or by applying pectoral muscle grafts to the myocardium. In advocating these procedures he overlooked the fundamental principle that neither scar tissue nor nonfunctioning muscle can maintain an effective blood supply. There is also no reason to suppose that more elaborate methods, such as Beck's (1948) recent proposal to anastomose an artery with the coronary sinus, can give such a significant improvement in coronary circulation as to justify so difficult a surgical manipulation.

Similar objections formerly applied to Blumgart, Levine, and Berlin's (1933) efforts to reduce the oxygen requirements of the arteriosclerotic myocardium by lowering basal metabolism. Total thyroidectomy proved to be a greater hazard than cardiac denervation. Furthermore, the reduction in metabolism necessary to ensure reduction of the work of the heart to a degree compatible with the myocardium's diminished supply of blood often led to severe symptoms of myxoedema. Graded destruction of thyroid tissue by the radioactive isotope of iodine (I^{131}) has, however,

made it possible to accomplish this in a safe and fairly effective manner. This has been demonstrated by the recent promising reports of Blumgart, Freedberg, and Kurland (1950, 1951), Blumgart and Freedberg (1952), Rosenfeld (1951), and Wolferth, Chamberlain, and Mead (1951). These writers have shown that the degree of hypothyroidism required in euthyroid patients with angina pectoris can be regularly induced by one or more injections of I^{131}. No serious toxic or untoward reactions have occurred. According to Blumgart *et al.* (1951), approximately one third of the patients have shown an excellent response, another third a definite improvement in their attacks of pain, while the results in the remaining third have been poor. In each case thyroid extract must be given to maintain a metabolic level at which there is maximum relief from anginal attacks and the minimum discomfort from myxoedema (a basal metabolic rate of −20 to −25 per cent). A few individuals have not been able to tolerate the discomfort of myxoedema of a degree sufficient to prevent their attacks, so that it has been necessary to give thyroid extract to elevate their metabolic rate to a point where pain is no longer relieved. It is not yet certain that the elevation of cholesterol in the blood that accompanies myxoedema may not lead to further damage of the coronary arteries nor that the potential late effects of radiation may not lead to carcinogenesis. Observations to date, however, have given no grounds for these fears. Judging from the reported results, the relief of anginal pain is approximately equivalent to chemical blocking of the cardiosensory nerves with alcohol, but not as effective as surgical denervation. The risk of mortality, which runs from 10 to 15 per cent after neurosurgical intervention, is nearly eliminated, but at the price of more or less lasting discomfort from myxoedema. It would therefore appear that a considerable number of patients with severe anginal pain can be spared the risk of surgical denervation, but that this will still be required for those who cannot tolerate the necessary degree of hypothyroidism and certain others with unusual forms of cardiac pain. Furthermore, cardiac denervation still seems to us to be the preferable procedure for the younger, good-risk subject who wants to be relieved of his anginal attacks and still be able to carry on a fairly active executive or medical career (see summaries on Patients 61A, 6B, 73A, and 1C).*

a. Chemical block:—Paravertebral injection at the sides of the upper four thoracic vertebrae was first proposed by Mandl (1925 B and C). He obtained temporary relief of anginal pain with procaine and Swetlow (1926

*Patients with A after the case number are in the group injected with alcohol. A detailed tabulation of these 77 consecutive cases is not given here, but can be found in the paper by White and Bland (1948) and the case numbers used here are from that table. Patients with B-numbers are all to be found in Table XLVI. These were treated by sympathetic ganglionectomy and the C group by cutting the roots of the corresponding posterior spinal nerves.

A and B) lasting benefit with 95 per cent ethyl alcohol. Because the point of attack was shifted from the cervical region caudally to include the thoracic cardiac nerves, it became the first effective method for interrupting the entire complex of fibres which transmit pain from the heart. We shall, therefore, discuss it first. Patients who have had frequent or recent attacks of coronary thrombosis are poor risks for anaesthesia and any form of open surgical intervention. For these paravertebral injection of alcohol is the least dangerous method of interrupting the pathways of cardiac pain. We have seen patients undergo injection without complication and then succumb to a later operation (see protocol of Patient 39A, p. 628).

There are, however, serious objections to chemical blocking of the cardiac nerves. In the most skilled hands failure to interrupt a sufficient proportion of the afferent fibres occurs in some 10 per cent. Furthermore, there is an appreciable risk of mortality in the most advanced cases even with this procedure. The principal danger lies in the fact that injection must be carried out without anaesthesia in order to observe the development of paralysis of the upper thoracic sympathetic outflow by the appearance of a Horner's sign and a hot, dry hand. The moderate degree of discomfort and accompanying nervous strain have been sufficient to precipitate fatal coronary infarction in four of our patients. Two other men died in a similar fashion but, fortunately for us, a few hours before the injection was scheduled. The statement is attributed to John Hunter (Home, 1796) that his life was in the hands of "any rascal" who might make him lose his temper. This prophecy was fulfilled, as he died at a medical meeting after being provoked by one of his colleagues. In this critical group fear of being hurt is unfortunately an equally dangerous form of psychic trauma. Adequate preliminary sedation of the patient serves to minimize this risk, but does not abolish it altogether. We have recently tried putting the patient to sleep in his bed before he is moved to the operating room with minimal dosage of Pentothal intravenously, supplementing this with inhalation of a low concentration of Trilene while the needles are inserted and their position verified by x-ray. The actual injection of procaine and alcohol must be carried out with the patient awake, but this should be painless and the patient is spared most of the nervous stress and discomfort connected with the procedure. While it is still too early to be certain, our preliminary experience has been most satisfactory.

Another danger, which can be avoided, is injury to the spinal cord if the alcohol penetrates the subarachnoid space. This complication has fortunately not occurred in our series of 77 cases (many of which have had multiple injections), and we believe that it can be avoided if the recommended precautions are scrupulously followed. Myelitis has, however, been re-

ported on three occasions (Molitch and Wilson, 1931; Olsen, 1941; and Hirschboeck and Gillespie, 1942).

Neuralgia due to irritation of the adjacent intercostal nerves is another problem. The sympathetic ganglia lie so close to the intercostal nerves that alcohol infiltrated around the chain cannot help bathing their trunks. This produces a certain amount of discomfort in nearly all cases and is a source of major complaint in some 10 per cent, but it can be counted on to clear up within a month or two.

A final point against the substitution of alcohol in place of surgical neurectomy is the fact that the block is not always permanent. Although 48 individuals maintained their initial improvement for periods up to 11 years after paravertebral injection, there was a recurrence of anginal pain after intervals of from two and one-half months to five years in 14 others. Judging from the temporary relief achieved by injection of alcohol in trigeminal neuralgia, it is surprising that the interruption of pain in angina pectoris has been of such long duration. With recent improvements in the technique of injection, and especially with radiological localization of the needles prior to injection, failure to secure a satisfactory chemical block is certain to become less frequent.

In spite of these cogent objections, the relief of suffering and the general improvement seen in so many of our patients have convinced us that paravertebral injection with alcohol still has a valuable role in the treatment of the more advanced stages of coronary heart disease with unbearable angina pectoris. Mastery of the technique is well worth the effort required because it enables so many otherwise hopeless sufferers to obtain relief from their pain.

Injection experiments in animals have shown that 5 cc. of alcohol produces an area of necrosis not much over 1 cm. in diameter. Observations made during two postmortem examinations have shown that this likewise applies to man. The infiltration of alcohol must, therefore, be far more exact than when procaine is used, as the latter diffuses so much more widely through the retropleural tissues. It is always evident when the alcohol has been correctly placed, because of the unequivocal signs of paralysis of the upper thoracic sympathetic rami. When these signs persist, pain is as effectively relieved as though the same structures had been resected. Even if there is a gradual disappearance of the Horner's sign and a reduction of the initial vasomotor and sudomotor paralysis, regeneration of the cardiosensory fibres is not likely to take place.

b. Sympathetic ganglionectomy:—This operation is best performed through the posterior approach with resection of the central end of the second rib (preferably of the third as well) and transverse processes (see

Fig. 98, p. 343). Ether-oxygen anaesthesia is administered through an intratracheal catheter. White and Smithwick (1941) formerly advocated use of the anterior approach, but we have since found that the posterior incision gives a far more direct exposure and permits the necessary extrapleural resection from the inferior cervical ganglion to a point well below the third thoracic. When the inferior cervical and first thoracic components of the stellate ganglion are separate as a dumbbell-shaped structure, removal of the lower portion is sufficient, but when fusion has taken place the entire ganglion should be resected. It is never necessary to carry the resection upwards into the cervical region, but it is essential to follow the chain downwards to include at least the third thoracic ganglion (see protocol of Patient 6B below). It is advisable to resect the fourth ganglion as well, if possible, as aberrant low fibres may occasionally run at this inferior level, and late recurrent pain from regeneration is less likely to develop after more extensive resections of the chain (cf. Patient 6B).

These sympathectomies should be done with the patients in the semilateral position. This permits much freer respiratory excursion and minimizes the danger of falls in blood pressure and consequent risk of coronary infarction, which are a hazard in elderly obese patients in the prone position. In experienced hands operation in the lateral position is no more difficult and the entire procedure can be performed in a little more than an hour.

Thanks to the improvements in anaesthesia by the intratracheal route and better position, which ensure far more effective aeration and better venous return to the heart, we are constantly expanding the indications for open surgical denervation. Lindgren and Olivecrona's (1947) large series of 73 cases with only five deaths has been a great incentive to this. Actually one wonders whether the minimal physical disturbance of chemical block is not more than offset by the emotional shock and discomfort to the conscious patient. Whereas before the war we employed paravertebral block in 75 patients and operated on only six, in recent years we have favoured operation over injection (11 ganglionectomies and one posterior rhizotomy to two injections).

For the surgeon who is experienced in the technique of sympathectomy, ganglionectomy is unquestionably the best for patients whose anginal attacks are referred to a single arm. When the distribution is bilateral there is little to choose between ganglionectomy in two stages and the slightly more major procedure of laminectomy, which permits division of the posterior roots on both sides at a single operation. The only objections to the more specific sympathetic denervation are that: (1) if pain is bilateral or later appears on the unoperated side, a second ganglionectomy may have to be performed; (2) it is possible for sensory regeneration to take place

after a year or more, as exemplified by Patients 3B and 6B, even when the chain has been resected from a point well above the *inferior cervical* ganglion down to the fifth thoracic. In addition, a sympathectomy at this level produces a Horner's sign with partial ptosis and myosis.

c. Posterior rhizotomy:—The effectiveness of this procedure was first demonstrated in animal experiments by White, Garrey, and Atkins (1933), but has only recently come into use at the Massachusetts General Hospital because of the apparently groundless fear that it would be too much of an operation for the average patient with advanced coronary disease. We have been able to obtain reports of 30 such operations in which the relief from anginal pain was consistently complete (Table XLVII). There were three operative deaths. We have had a most satisfactory result from our own first trial.

These statistics show that the operation, performed under intratracheal administration of ether and oxygen in the semilateral position, is a comparatively safe procedure and one nearly certain to put an end to all pain felt in the precordial area or referred to either arm. The minimal number of posterior roots which should be sectioned are the upper four thoracic on both sides. Its advantages are that: (1) the technique of laminectomy and posterior root section is a standard operation and well understood by the average neurological surgeon; (2) there is no chance of regeneration; (3) the cardiac afferent fibres can be cut on both sides at a single operation.

These advantages are counterbalanced to a certain extent by the facts that: (1) Laminectomy of three vertebrae is a somewhat more time-consuming procedure than resection of the ganglia. (2) Bilateral root section, even if the blood vessels which accompany the nerve roots are carefully preserved, involves the occasional risk of an ischaemic myelopathy. This tragic complication has been reported after extensive bilateral anterior root section for hypertension (Page and Heuer, 1937), and it occurred in a case of severe hypertension after posterior rhizotomy for atypical cardiac pain performed by Mixter and White in 1934. (3) Laminectomy is usually performed in the prone position. This limits normal inspiratory excursion, thereby reducing negative intrathoracic pressure and the return of blood to the right side of the heart. Even with careful attention to placement of the patient on the operating table this is a distinct handicap, especially in an obese individual with coronary disease. It can be eliminated by performing the operation in the semilateral position, which we have practised and found satisfactory, even if the sensory roots are to be cut on both sides.

d. Selection of cases:—Surgical treatment of angina pectoris should be reserved for the victims of angina pectoris who cannot be controlled effectively on a medical regime. There is no longer any justification for per-

mitting a patient to suffer from continued angina decubitus, which carries the risk of physical and mental exhaustion with ultimate addiction to narcotic drugs. Under these circumstances cardiac denervation may actually prolong life by protecting the patient from pain during a particularly dangerous period of coronary insufficiency until the collateral circulation of the myocardium improves. This is at best a slow process, often requiring months before significant results are evident. In numerous instances these patients have ultimately been able to return to work as their coronary circulation improved, with only mild restriction of activity and considerable reduction in their need for nitroglycerine.

When the pain continues to be unduly severe the patient himself should be the final judge in the decision between continued dependence on drugs, with the necessary rigid limitation of his activity, and the more dangerous method of relieving his pain by surgery, with its more rewarding possibilities. He alone knows the exact degree of his discomfort and the mental disturbance induced by the fear of imminent death. It is therefore best to discuss the matter frankly with the patient and tell him the price he must pay in the way of risk and temporary discomfort in return for nearly certain freedom from pain and the likelihood of a considerable increase in his activity and enjoyment of life.

Once the decision has been made in favour of surgical intervention, the intelligent choice of the proper surgical procedure depends on the relative competence of the heart. Those with a fair cardiac reserve may be submitted to laminectomy and root section with reasonable safety. This operation is most logical when the reference of cardiac pain is bilateral or when the surgeon is not experienced in the technique of sympathectomy. For the more questionable risks, thoracic ganglionectomy is preferable, especially if anginal pain is unilateral. For the poorest risk cases, viz., those who have had repeated or recent attacks of coronary infarction (de Peyster et al., 1952), with large hearts and great reduction in cardiac reserve, or those with active rheumatic or syphilitic heart disease, interruption of the nerves by paravertebral alcohol block may be the only possible recourse, if surgery must be undertaken.

3. Clinical Results

a. **Results of paravertebral injection with alcohol:**—The results in 77 patients in whom this procedure has been used at the Massachusetts General Hospital are summarized in Table XLV. A more detailed table, listing all the individual cases, their pathology, result, and subsequent course is to be found in the article by White and Bland (1948). Among the 55.8 per cent listed as good results are included those patients who were com-

TABLE XLV

SUMMARY OF OPERATIVE RESULTS IN INTRACTABLE ANGINA PECTORIS

	No. of Cases		*Per cent*
A. *Paravertebral block with alcohol*			
Total personal cases:	77		
• Complete relief (later partial recurrence in 14):	43		55.8
Unclassified (excellent early result, but inadequate follow-up):	5		6.5
Worth-while improvement:	16		20 8
Failure:	6		7.8
Died in hospital:	7		9.1
B. *Thoracic ganglionectomy*			
Total personal cases:	17		
Complete relief of precordial and arm pain on denervated side:	13		76.5
Residual slight pain in neck and jaw:		2	
Late partial recurrence:		3	
Early failure (incomplete denervation):	1		5.9
Hospital deaths:	3		17.6
C. *Posterior rhizotomy*			
Total personal cases:	1		
Cases reported from other clinics (see Table XLVII):	30		
Complete relief on operated side:	27		87.1
Slight residual pain:	1		3.2
Deaths:	3		9.7

pletely or nearly completely relieved of their pain on the side of injection. The 20.8 per cent with fair results comprise a group in whom intractable angina pectoris was so reduced that the patients could be maintained in a state of relative comfort by routine medical measures without the use of narcotic drugs. *If we include the five patients in the group which are unclassified because of inadequate follow-up or other reasons (all of whom appeared to have had good results), over 83 per cent of the entire series obtained excellent to fair results, so that even the least satisfactory felt that they were distinctly improved; 7.8 per cent failed to derive adequate relief and are classified as failures; and 9 per cent died in the hospital following the procedure.*

Although the mortality rate is nearly equal to that following operation, it is important to bear in mind that this group includes the very worst risk cases with severe coronary disease, threatened decompensation, extreme old age, and other conditions which would have resulted in a prohibitive mortality had any neurosurgical procedure been attempted. Patient 39A, who came through a bilateral injection without any disturbance but subsequently succumbed to an operation on his gall bladder, is evidence to confirm this statement. Intercostal neuralgia, while a cause of minor discomfort of several weeks' duration in most cases, was a serious complaint in 10 per cent, in whom it was troublesome over periods of one to three months but ultimately subsided.

In recent years with improvement in injection technique the proportion of good results has increased steadily, so that the results in the latter third of the series are distinctly the best. The introduction of x-ray control in the placement of the needles barely antedated World War II and has therefore been tried in only a few cases. This ensures much greater accuracy in blocking the cardiac rami and will be reflected by still more impressive results.

In the group of patients who have had good initial results from chemical block, partial to complete recurrence of pain secondary to recovery of nerve conduction has been observed in 18 per cent after periods of from two and one-half months to five years but, on the other hand, most of the other survivors are known to have maintained full benefit for periods ranging up to 11 years. It seems remarkable that mere infiltration of alcohol could block the cardiac sensory fibres over such a prolonged period, as we have rarely observed the persistence of a Horner's sign, vasodilatation, or anhidrosis for over a year. Nevertheless, in four patients with persistent mild anginal attacks on the uninjected side there has been continued absence of pain on the side of injection for periods ranging from two to six and one-half years. In other cases, however, it is likely that the long lasting results were due, at least in part, to spontaneous development of a competent collateral circulation in the coronary vessels.

The following case histories illustrate the various forms of cardiac pain which have been treated and some of the more outstanding results:

Patient IA, William M., Old MGH #280719, 54. Syphilitic aortitis and aortic regurgitation with angina pectoris.

This patient was the first to be treated by paravertebral alcohol injection. He was a middle-aged carpenter who had had syphilis for many years. Nearly three years prior to admission he had his first attack of angina pectoris, and the pains were soon recurring three to four times a day. Syphilitic heart disease was diagnosed in the cardiac clinic. He was there discovered to have marked hypertrophy and dilatation of the left side of the heart with widening of the aortic arch. There was a very loud aortic diastolic murmur, in addition to a moderate aortic systolic and mitral systolic and a diastolic murmur of the Austin Flint type. His pulse was of the Corrigan type and the blood pressure was 170/35. An electrocardiogram showed inverted T-waves in the first and second leads, with left axis deviation.

The patient was admitted to the hospital, where he was kept in bed on medical treatment for over six weeks. During this period his angina increased in both severity and frequency. The most troublesome feature of his attacks was that they came for the most part at night, so that he became exhausted from lack of sleep. As a result the patient and his physicians finally concluded that he would die of exhaustion unless relief could be obtained by surgical means. This led Dr. P. D. White to urge a trial of para-

vertebral alcohol injection, which had recently been recommended by Swetlow (1926 A and B).

2/12/27: Diagnostic paravertebral procaine block, T1-T5 (left), resulted in freedom from his attacks for 36 hours, but not for the long period described by Mandl (1925 B and C). 2/21/27: Paravertebral alcohol injection, T1-T5 (left). The injection was performed without complication and gave the characteristic chest wall anaesthesia, but without a Horner's sign. He reacted differently from all our other patients in that he noted postoperative attacks of decreasing frequency for two weeks, after which he had no attacks on his left side. He was able to return home and lead a quiet life in comfort.

A year later milder attacks were recurring in his right arm and chest wall. An attempt was made to stop these by a right-sided injection by another surgeon, but this block and another later attempt were unsuccessful. He was then followed in the out-patient clinic, and remained altogether free of left-sided pain and without too great discomfort on the right, where the attacks could be relieved by nitroglycerine. Finally in 1933 cardiac failure developed, from which he died. No autopsy was performed. The relief of his unbearably severe left-sided angina pectoris had lasted over six years.

Patient 35A, Evelyn C., Old MGH #337315, 26. Rheumatic heart disease with free aortic regurgitation and angina pectoris.

The patient had rheumatic heart disease with marked cardiac enlargement, free aortic regurgitation, blood pressure of 170/50, mitral stenosis and regurgitation, and angina pectoris decubitus. Severe rheumatic fever and heart disease began at the age of nine years. A recrudescence of rheumatic fever occurred at 16, requiring hospitalization for 12 months. She subsequently did well and remained free of symptoms except for moderate exertional dyspnoea and palpitation until the age of 26, when she re-entered the hospital with another recrudescence of rheumatic fever. While at rest in bed she began to have severe angina pectoris.

Her attacks were characterized by paroxysmal discomfort due both to pain and to associated circulatory phenomena. The sequence of events began with a consciousness of forceful regular heart action and a sense of throbbing in the throat, accompanied by an increase in the pulse rate from a resting level of 90 up to 130 or 140 per minute. In one to two minutes an aching precordial pain appeared, rapidly becoming severe and spreading upward in the chest and down the left arm as far as the wrist. Respiratory discomfort and a sense of choking were usually present, as well as profuse sweating and generalized flushing of the skin. A blood pressure determination was not made during an attack. Occasionally dyspnoea and palpitation occurred without pain, but never the reverse. Although precipitated by emotion or exertion, the attacks most frequently occurred without provocation, especially during the night. The severe anginal pain was usually superimposed upon a less intense precordial aching sensation similar to that

frequently described by patients during active rheumatic fever. Nitroglycerine gave partial relief, but it was this latter component of the patient's discomfort which remained uninfluenced by the drug and for which morphia was frequently required.

5/31/34: Paravertebral alcohol injection, T1-T4 (left). There resulted a well-marked Horner's syndrome, a transient partial anaesthesia over the left chest anteriorly, and a variable paraesthesia over the left upper back and down the inner aspect of the left arm. This was followed by complete relief from anginal pain during frequent attacks, the presence of which was made known by a tightening sensation in the throat and a persistence of the accompanying palpitation, respiratory discomfort, and generalized flushing of the skin. However, another important element in addition to the pain had been dispelled, namely, the fear of an impending attack. It is of considerable interest that the precordial ache, which previously had not responded to nitroglycerine, persisted off and on in a modified form, but on the whole was less severe and frequent. This component appeared to be directly related to the active rheumatic disease and subsequently disappeared.

The patient was seen at frequent intervals and was examined in June, 1936, two years after the injection. She was in good condition and was free from clinical and laboratory evidence of active rheumatic infection. There remained a slight residual Horner's syndrome and a vague sense of numbness over the precordial area, with slight paraesthesia along the inner aspect of the left upper arm. She led a quiet life and was able to do light household work. About once a week she had to pause for a few minutes because of tightening in the throat and thumping of her heart, but this was now always related to unusual exertion or excitement.

Nearly four years after the injection the patient developed subacute bacterial endocarditis, from which she died. She remained free of her old anginal attacks throughout.

Patient 39A, James I., 63. Arteriosclerotic heart disease, previous coronary infarction, and angina pectoris.

This patient was seen in the University Hospital, Charlottesville, Virginia, in consultation with Drs. A. D. Hart and J. E. Wood. His angina pectoris dated back over an eight-year period, but he was able to get along quite comfortably on medical treatment until the spring of 1935. At that time he had a fairly severe attack of coronary thrombosis, from which he made a slow convalescence, but thereafter his anginal attacks became more severe, increasing in frequency up to 30 or 40 a day. The attacks radiated to both arms and were especially severe at night. He had been in the hospital for over a month while unsuccessful attempts were made to give him rest at night with oxygen inhalations and opiates. The patient was obese. He had moderate peripheral arteriosclerosis and a blood pressure of 170/95. The cardiac dulness could not be determined with great accuracy, but it was thought that

the heart was enlarged. Its sounds were of fair quality and there were no murmurs. As it was believed that the patient could not long survive the exhaustion brought on by his loss of sleep from pain, it was hoped that bilateral alcohol injection might give him much needed relief.

10/8/35: Paravertebral alcohol injection, T1-T4 (left). 10/9/35: Paravertebral alcohol injection, T1-T4 (right). The patient came through both injections with a minimum of discomfort and proceeded to recover in a way that exceeded all our hopes. He never had another attack of cardiac pain, but continued to have a satisfactory warning signal, which consisted of a sense of oppression in his suprasternal notch. With adequate sleep he was soon able to leave the hospital, and in a remarkably short time to resume his mild activities in his store. When seen six months later he was at work and free of pain.

Unfortunately, 10 months after injection he had a flare-up of an old subacute cholecystitis, for which his medical advisers were not consulted. Operation, which was performed at another hospital, resulted in an early death from congestive failure.

In commenting on this case his physician, Dr. J. Edwin Wood, wrote as follows: "I would not hesitate to say that Mr. James I.'s relief following paravertebral block was as nearly complete as anything I have ever seen. His relief was so complete, in fact, that he was back at work in a relatively short time and experienced no discomfort while at work. He told me that on occasions with exceptional exertion, i.e., exceptional for him, he could feel perhaps a little pressure sensation in his chest which he rather felt was a warning and was pleased that it was there... Mr. I.'s life was unquestionably prolonged by the paravertebral block and I feel that if he had not insisted on the gall bladder operation he would have had a number of months and perhaps even years ahead of him. It was truly amazing to see him back at work in the grocery store after having followed him for some weeks in a perfectly miserable state."

The next two case histories illustrate equally dramatic recoveries from states of totally incapacitating angina pectoris with recovery of normal activity and long survival:

Patient 51A, Mrs. Amelia F., 66. Hypertensive heart disease and angina pectoris.

This woman, referred by Dr. Robert L. Levy, had suffered from attacks of left-sided angina pectoris for 10 years. These became much worse following an infarction in 1936, so that she was restricted to her room and required morphine for relief of the pains, which failed to respond to nitroglycerine or codeine. These attacks often occurred in bed and she was losing sleep and weight. The electrocardiogram had shown progressive changes with inversion of T1 and T2 and upright T4. There were left ventricular preponderance and a slow rate from 40 to 60.

4/17/37: Left paravertebral injection, T1 to T4, was performed in her

room. She was able to be up on the following day and had a minimal degree of neuralgia during the next few weeks. With the disappearance of her anginal attacks she no longer suffered from insomnia and her weight and cardiac reserve were regained rapidly.

Nine years later Dr. Levy reports: "She is now 75 years old. . . In her case the injection of alcohol remade her entire life. She has been completely *free from cardiac discomfort for several years.* She is very active and is a director of the . . . Home for Old People. She goes out to dinner two or three times a week and plays bridge frequently. She goes to the theatre and the movies. She is happy and in remarkably good health for a woman of her age. The last electrocardiogram was made on April 14, 1943. At that time there was a well-marked sinus arrhythmia and left axis deviation. There were no changes indicating myocardial damage. The blood pressure was 154/86. It is my opinion that the injection prolonged this patient's life, although this point would be difficult to prove."

The improvement in the second electrocardiogram reported by Dr. Levy is noteworthy.

Patient 61A, Reginald R., MGH U-158329PH, 46. Arteriosclerotic heart disease with coronary occlusion and angina pectoris.

This retired Army officer was referred to us by Dr. H. M. Marvin of New Haven. Since the last war he had had "soldier's heart" with easy fatigue, dyspnoea, and palpitation. Seven months before he had a sudden attack of precordial pain with radiation to both arms, which required morphine for relief. Three months prior to admission he had another severe attack of precordial pain. He then began to suffer frequent and intense attacks of bilateral angina pectoris. As this patient was a high-strung, strenuous man, he *reacted poorly to inactivity and could not be controlled by medication.* His heart was not enlarged, sounds were of fair quality, no murmurs, rate and rhythm were normal. Electrocardiogram showed inverted T-waves in leads 2 and 3, with a normal chest lead.

10/27/38 and 10/29/38: Left and right-sided paravertebral injections of alcohol. These were followed by more than the usual degree of neuralgia, as had been anticipated from his nervous make-up, but the thoracic discomfort subsided in a little over a month. He then returned to Bermuda.

Six months later he reported that he was "working and exercising almost normally." Two years after injection he was able to pass his Army medical examination. On nervous or physical strain he experienced a warning signal which consisted of "slight congestion on the sides of the throat or aching in the left arm like rheumatism." In January, 1941, his local doctor reported him to be "absolutely *well in all respects.*" At the onset of the war he tried to return to active service and would have been reinstated in his commission had it not been for the past history of angina pectoris. In June, 1945, he was reported lost at sea while cruising alone in a small sailboat off Bermuda.

b. Results of upper thoracic ganglionectomy:—Study of the statistics summarized in Table XLVI shows that resection limited to the upper three thoracic ganglia is nearly certain to afford complete relief of pain on the side of operation, but failure to remove this extent of the chain is likely to be followed by return of anginal attacks. In Patient 6B, after a resection from the stellate through the second thoracic ganglion, the gradual return of ipsilateral precordial pain necessitated a secondary resection of the third thoracic ganglion. In Patient 14B failure to remove this ganglion resulted in an early recurrence of anginal attacks. In one of our earlier cases, Patient 3B, there was late recurrence of pain referred to the arm and possibly some return in the left precordial area. In Patient 6B (see protocol below) there was also a return of precordial pain three years after operation on the right side, where the resection had included the upper three thoracic ganglia. At six years she developed further pain on the left side, despite the fact that the chain on that side had been resected from well above the inferior cervical down to the fifth thoracic level. The return of mild anginal attacks on each side was coincident with recovery of sweating in the corresponding arm. All the other survivors have remained free of pain for periods up to seven years, with the exception of Patient 13B, who has recently reported recurrence of some mild left-sided pain on exertion. This first became noticeable some four years after operation.

There have been three early postoperative deaths and one that occurred on the operating table. This case, Patient 15B, had electrocardiographic evidence of coronary disease, although there had been no definite episode of coronary thrombosis. He had a very low tolerance to exertion, and operation was undertaken in preference to alcohol injection only because of the patient's dread of remaining awake during the procedure. He arrived in the operating room worried and having slept poorly, and then proceeded to have a severe attack of angina as anaesthesia was being induced with Pentothal. In retrospect, the operation should have been given up, but he was intubated and given ether-oxygen, as the blood pressure remained stable. Thirty minutes afterwards, as the chain was being exposed, the blood pressure fell, with immediate cessation of respiration and heart beat. Attempts at resuscitation proved fruitless. Operation in this 57-year-old man, undertaken at the patient's insistence after 12 years of suffering from anginal attacks, must be regarded as a surgical error in judgment. To-day this poor-risk case could be treated by medical thyroidectomy with I^{131} with safety and a good chance of success. If operation had to be performed, he should have been given intravenous Pentothal in his bed before being moved to the operating room.

Death in Patient 2B occurred suddenly on the day he was to be discharged. His convalescence had been uneventful and postmortem showed

TABLE XLVI

RELIEF OF PAIN IN SEVERE ANGINA PECTORIS BY UPPER THORACIC SYMPATHETIC GANGLIONECTOMY

Patient	*Age*	*Etiology*	*Operation*	*Relief*	*Activity after Operation*	*Follow-up Period*	*Cause of Death*	*Pain at Death*
1B. Giuseppe G.* Old MGH #270156	20	Rheumatic heart disease with aortic and mitral lesions. Severe long-lasting attacks of angina pectoris, especially at night.	2/5/29: T1-T2 (L)	Good.	Overactive in business despite painless warning signal. Took no care of himself.	7½ mos	Cardiac decompensation	Right side only.
2B. Charles A.* Old MGH #301517	29	Syphilitic aortitis and aortic regurgitation, angina pectoris with radiation to both arms.	9/19/29: T2-T4 (L)	Good.	Survival period too short to evaluate.	12 days	Postmortem: Luetic occlusion coronary orifices, total on R., 50% on L.	Right side only.
3B. Augusta B.* Old PH #20964	60	Arteriosclerotic heart disease with coronary involvement.	10/1/29: T1-T3 (L)	Good.	Led active life but suffered partial recurrence after first year.	5 yrs.	Probable coronary thrombosis.	+
4B. Nathan O.* Old MGH #305234	62	Arteriosclerotic heart disease with coronary infarction.	3/19/30. T1-T3 (L)	Good.	Survival period too short to evaluate.	1 mo.	Empyaema secondary to postoperative pneumonia	0
5B. Elizabeth P. MGH U-187903BM	58	Arteriosclerotic and hypertensive heart disease.	7/5/39: T1-T3 (L)	Good.	Moderately active life with mild attacks in lower jaw at 15 mos.	15 mos.		
6B. Dr. E. W. MGH U-324210BM	44	Hypertensive heart disease with severe bilateral angina pectoris and drug addiction	10/22/41: Inf. cerv.-T2 (L) 12/15/41: T1-T3 (R) 4/6/43: T3-T4 (L)	Fair. Good. Good.	Continued practice of medicine with only mild residual pain in lower jaw. Partial recurrence of R. precordial pain at 3 yrs. coincident with reinnervation of sweat glands. Two years later recurrent pain developed on L.	7½ yrs.	Sudden death following day of work with much precordial pain.	+
7B. Charles C. USNH, Chelsea	47	Arteriosclerotic heart disease with angina decubitus and severe right-sided angina pectoris.	4/13/42: T1-T3 (R)	Good.	Restricted activity for 7 yrs. but able to drive truck in warm weather.	7 yrs.	Sudden death at home. Probable coronary thrombosis.	
8B James T. USNH, Chelsea	44	Arteriosclerotic heart disease with coronary involvement.	6/3/43: T1-T3 (L)	Good.	Active work as tax investigator at 5 yrs. Little need for nitroglycerine.	5 yrs.		

9B. Mabel P. MGH U-557903	53	Rheumatic and hypertensive heart disease, paroxysmal auricular tachycardia, coronary thrombosis, with left-sided angina pectoris	11/4/46: Inf cerv -T5 (L)	Good.	Remarkable transformation, as she has only had 2 short runs of tachycardia and no further pain. Now able to lead normal life.	2 yrs.	
10B Evelyn W. MGH U-595030	56	Arteriosclerotic heart disease and coronary infarction with left-sided angina pectoris.	11/4/47: Inf. cerv.-T3	Good.	Remained free of pain to death.	7 mos.	Probable coronary thrombosis.
11B. John M. MGH U-601372BM	63	Arteriosclerotic and hypertensive heart disease with coronary infarction.	1/22/48. Inf. cerv.-T4 (L)	Good.	Uneventful convalescence till painless sudden death on fifth postoperative day	5 days	Postmortem: Extreme sclerosis of coronary arteries, old myocardial scar, and fresh apical infarct.
12B. Donald M. Cushing VAH	57	Arteriosclerotic heart disease with bilateral angina pectoris, L. side more involved.	2/4/48: Inf. cerv.-T2 (L)	Good.	No further pain during month's period of observation in hospital.	1 mo.	
13B. Muriel N. MGH U-606943BM	43	Arteriosclerotic heart disease with left-sided angina pectoris.	2/16/48: Inf. cerv.-T3 (L)	Good.	Pain free and able to be much more active for 3 yrs. Now still active but some return of angina pectoris.	5 yrs.	
14B. Floyd W. MGH U-594142PH	59	Hypertension and arteriosclerotic coronary disease with left-sided angina pectoris.	9/19/49: T1-T2 (L) Difficult and inadequate denervation.	Good.	Early recurrence of pain.	3 yrs.	
15B. Ralph M. MGH U-692545	57	12-year history of arteriosclerotic heart disease with severe left-sided angina pectoris.	3/12/50. T1-T4 (L)		Operative death		Acute cardiac arrest.
16B. Dr. J. B. MGH U-696296	55	Three episodes of coronary thrombosis over 3 yrs., followed by anginal attacks, severe on L, mild on R.	4/10/50: T1-T3 (L)	Good.	Continues practice of surgery. No further left-sided pain. Right-sided attacks have increased but patient reluctant to have further surgery because of postoperative neuralgia.	2½ yrs.	
17B. Lee T. MGH U-730716BM	52	Suffering from left-sided anginal attacks for 12 yrs. which had become intolerable. Coronary disease.	3/15/51: Inf. cerv.-T4 (L)	Good.	No medication or pain. Continues business and all activities short of athletics.	1½ yrs.	

the cause of death to be extensive syphilitic aortitis with occlusion of the coronary ostia. Nevertheless it is impossible to say that operation did not hasten his demise. The remaining death (Patient 11B) occurred on the fifth day following an uneventful operation. The patient had been up and perfectly comfortable, but developed a rapidly fatal coronary occlusion while straining at stool. His death was painless. Postmortem examination showed extreme sclerosis of his coronary arteries and a large fresh apical infarction.

Another death must be attributed directly to surgery, although it occurred outside the hospital a month after operation. Patient 4B developed a staphylococcus aureus wound infection and pneumonia, from which he apparently made a good recovery and was discharged after 27 days. A week later, however, he died of a painless coronary occlusion. Post-mortem examination showed a small encapsulated empyaema in the paravertebral gutter. There were sclerotic plaques which had caused extensive occlusion of both the right and left coronary arteries, with areas of old and recent infarction. Postoperative infection was undoubtedly the precipitating factor in his death. Another such complication should now be preventable by chemotherapy.

The following case histories illustrate a number of interesting features in regard to the extent of neurectomy necessary to ensure complete interruption of anginal pain and the striking degree of improvement in the patient's physical and psychic condition which follows relief.

The first shows the completely ipsilateral effect of a left-sided denervation by the fact that during the eventual fatal coronary attack intense pain radiated to the right arm and right anterior chest but never crossed the midline:

Patient 1B, Giuseppe G., Old MGH #270156, 20. Rheumatic heart disease, mitral and aortic stenosis and regurgitation with angina pectoris.

This young man first entered the hospital with rheumatic fever in 1925. At that time he already had signs of severe cardiac involvement with free aortic regurgitation. In 1928 he experienced precordial pain on drinking cold water. Since then the attacks had remained localized to the left precordium but increased in number and severity. They were particularly troublesome at night, averaging four to six attacks, and lasting as long as an hour,

Dr. P. D. White's examination revealed a pale, thin young man with bounding arterial pulsations in his neck, a thrill over the great vessels, and both systolic and diastolic aortic murmurs. There was no evidence of cardiac failure. The heart was moderately enlarged. Electrocardiogram showed a diphasic T2 and left axis deviation.

1/28/29: Diagnostic procaine block of first and second thoracic ganglia, followed by relief for twenty-four hours.

2/5/29: Resection of central end of second rib with first and second thoracic sympathetic ganglia on left side by Drs. W. J. Mixter and J. C. White. The patient made a smooth convalescence. His left-sided anginal attacks were permanently relieved, but he continued to have mild bouts of pain in his right chest, which served as a warning signal. He left the hospital, continuing to work as an insurance agent and to lead a fairly active life for the next eight months. He was then forced to re-enter the hospital on account of progressive dyspnoea. On the third day he developed fatal coronary insufficiency with severe pain, which was observed from its onset. The remarkable feature of this attack was the distribution of his pain, which was confined entirely to the right side of the anterior chest and stopped exactly at the midline. Postmortem examination could not be obtained.

The next case history illustrates the difficulties which may be encountered by peculiar reference of pain to the head and jaw. The typical anginal pain in the chest and arm was relieved by resection of the inferior cervical and upper thoracic ganglia, but the unusual radiation to the trigeminal and upper cervical dermatomes was not interrupted either by resection of the superior cervical ganglion or by subsequent division of the superficial branches of the cervical plexus. In retrospect, however, it seems probable that the cervical radiation could have been relieved by a C2 to C4 sensory root section and the pain referred to her lower jaw by mandibular block.

Patient 5B, Mrs. Elizabeth P., MGH U-187903BM, 58. Arteriosclerotic and hypertensive heart disease with angina pectoris.

Mrs. P. had a striking hereditary background of degenerative vascular disease. She herself had had high grade hypertension for the past 12 years without complications. For the past three years she had suffered from angina pectoris. The attacks, which were localized to the left side, involved the precordium and arm in the usual manner; in addition, pain radiated to the forehead, where it was felt behind the eye, to the upper and lower jaws, and also to the neck and posterior scalp. Before entering this hospital she had been treated by Dr. H. M. Marvin by rest in bed for several months without relief. Dr. Marvin then referred her to us for operation.

The patient was an intelligent and most cooperative woman of slender build. Physical examination showed tortuous radial arteries and a blood pressure of 270/130. There were no signs of congestive failure. By x-ray the left ventricle was slightly enlarged and the aortic arch tortuous. The electrocardiogram showed "coronary" T-waves.

5/10/39: Resection of the left inferior cervical, first and second thoracic sympathetic ganglia. The resection, made through the supraclavicular approach, was followed by an uneventful convalescence. The attacks of precordial and arm pain were relieved, but she continued to feel pain radiating to her neck, scalp, and face.

7/5/39: Resection of the left superior cervical ganglion. Following this operation, which divided some of the branches of the superficial cervical plexus, the skin of her neck was at first anaesthetic. During this period she had no real pain, but noticed clutching sensations in her throat and some discomfort in the left side of her face on over-exertion. As cutaneous sensation in her neck recovered, pain again recurred in this area and became particularly troublesome in the left occipital area. Because she had experienced relief during the period of cutaneous anaesthesia, it seemed logical to try the effect of permanent denervation of the area to which this unusual pain was referred. This was accomplished by resection in two stages of segments of the great occipital and other branches of the superficial cervical plexus, but was followed by only a transitory period of relief. A year and a half later the patient wrote that the first operation "removed completely all pain from the lower chest, over the heart, and in the arm. . . I can truthfully say that in spite of the fact that the last two operations have numbed superficial areas, they have not prevented the recurrence of the deep pains" in the base of the neck, chin, and posterior scalp.

The third case history is particularly instructive because it shows the unimportance of removing the lower cervical ganglia, but the vital need for carrying the resection caudally to include at least the third thoracic ganglion. While this is not always necessary, as demonstrated by Patients 1B and 12B, its neglect will certainly result in persistent low precordial pain in a fair number of cases. In addition this case history demonstrates the possibility of regeneration of afferent cardiosensory fibres as well as return of vasomotor and sudomotor activity to the face and arm after even extensive resections of the sympathetic chain.

Patient 6B, Dr. E. W., MGH U-324210BM, 44. Hypertensive heart disease with bilateral angina pectoris and morphine addiction.

This woman physician, referred by Dr. H. M. Marvin, came from a family predisposed to cardiovascular disease. She suffered a coronary occlusion in 1939 and thereafter developed frequent attacks of crushing pain in the precordium with radiation to both arms. Nitroglycerine would abort but failed to relieve the attacks, for which she had taken opiates, and she had developed a definite drug addiction. Examination revealed a nervous, high-strung woman who was suffering severely from insomnia and pain, so that she had been taking increasing doses of Dilaudid and Nembutal over the past two months. Her heart was normal as to size and sounds. Blood pressure was 160/110. The electrocardiogram showed evidence of slight left ventricular strain.

10/22/41: By the supraclavicular approach the middle and inferior cervical with the upper two thoracic sympathetic ganglia were resected on the left side. It had been intended to include the third thoracic ganglion, but a low resection of the chain in this thick-necked woman proved difficult, and

the postoperative x-ray revealed that the dural clip placed on the chain at the point of resection lay rostral to the third rib. After this operation there was relief of all pain on the left except for a slight residual distress under her breast, but with continued right-sided attacks her convalescence was complicated by psychic changes secondary to drug addiction.

12/15/41: Posterior approach through second rib with removal of upper three thoracic ganglia on right side. Convalescence after the second operation in the absence of painful anginal attacks was more satisfactory. Her warning signal now consisted of episodes of painless dyspnoea. After a period of two months' psychiatric rehabilitation she returned to her home and practice. She was then able to continue an office practice for a period of seven months, when she had what appeared to be another coronary occlusion. Thereafter she again began to complain of pain low in the left precordium, owing to our failure to resect the third thoracic ganglion. She was readmitted at her own request to complete the denervation of the left side of her heart.

4/6/43: Resection of third and fourth thoracic ganglia on left through third rib approach. An additional 4 cm. of the paravertebral chain was removed, including the dural clips applied to the distal stump at the previous intervention. Convalescence was uneventful and nursing care far less difficult than at her former admission. *Fifteen months later she reported that* she had no precordial pain, but adequate warning signals on over-exertion. These consisted of a "slight, but really indescribable sensation in the chest where the old bouts of pain used to be," and some mild but definite pain referred to her neck and lower jaw. "I am more comfortable than I have been in six years. Walking is out, but I can drive without difficulty. . . Following my doctor's advice, I only practice about three hours daily. . . Last electrocardiogram is not appreciably changed."

In 1944, three years after her initial operation, she reported that she never had any precordial or arm pain, but that if she over-exerted she was "brought up shortly by pain in the neck and jaw. This as a rule is quite bearable and passes in a couple of minutes. . . I put in an average of six very busy hours daily in medical work. . . I have noticed in the last few months that when I have an occasional severe attack there is a slight crushing in the chest on the right side. Shortly after noticing this for the first time I observed that such attacks were accompanied with some perspiration of the upper half of the right side of the face and slight moisture of the right palm. . . In 1941 I felt that I had reached the extreme limit of my endurance and now I am again living a full life."

In the next few months following this letter she reported that her recurrent pain had become more severe and partially incapacitating. She was beginning to consider returning to Boston for further surgery when she had a third coronary thrombosis. This was fortunately not severe and by happy chance the infarct must have wiped out the reinnervated area giving rise to her pain. Again she became free of anginal attacks and returned to practice.

Relief, however, was of short duration. She continued to work despite recurrent attacks of coronary thrombosis and considerable pain in her chest and arms. Sudden death terminated her gallant fight six and a quarter years after her last operation.

A final case history in this series is of particular interest because the results of a purely right-sided denervation for this unusual distribution of anginal pain were so satisfactory.

Patient 7B, Charles C., 47. Arteriosclerotic heart disease with angina decubitus (right-sided pain).

This veteran of the first World War was seen at the U. S. Naval Hospital at Chelsea at the request of Dr. James Faulkner. He had been incapacitated for work by angina pectoris for 13 years and complained of deep-seated pain on exertion in his right anterior chest with radiation to his right arm and neck below his ear. For six years he had suffered periods of angina decubitus each winter. For the last few months he had been forced to remain in bed and was frequently awakened from sleep. As nitroglycerine was no longer effective, he was requiring morphine in increasing dosage. Except for the fact that he was a steady drinker, his past history was uneventful, but his father had died at 51 of "heart disease." There was no history of syphilis and his Kahn reaction was normal. General physical examination was not remarkable. Blood pressure 130/94. The heart was not enlarged, but the sounds were indistinct and there was a late systolic murmur at the apex. The electrocardiogram showed T2 upright but low, T3 inverted, and a slight delay in A-V conduction. When an anoxia test was performed with 10 per cent oxygen and 90 per cent nitrogen, substernal pain developed in six minutes with depression of the S-T interval and a diphasic T4.

4/13/42: Right-sided resection of the lower portion of the inferior cervical and upper three thoracic ganglia through a posterior second rib approach. Convalescence after this operation was quite uneventful. Three weeks later on repeating the anoxia test there was no longer any pain on the right side or any change in the electrocardiogram. The patient noticed mild discomfort only on the left side of his chest.

A year later, in answer to a follow-up letter, he stated that he had not had any pain on his right side at any time. "I get a warning, which affects me with a constricting sensation at the base of the throat and a cramping sensation high and to the left of the breast bone. These attacks do not last, as they did before, and usually disappear after a short period of relaxation and a nitroglycerine tablet." Although his activity was much restricted, he was able to drive a truck in warm weather. He remained free of pain until seven years later he was reported to have died suddenly.

Of the last 12 patients submitted to thoracic sympathetic ganglionectomy since 1941, eight are known to have remained free of anginal attacks over intervals from one month to seven years. Six have been able to return

to work and lead moderately active lives. Patient 6B, although freed of her severe attacks and morphine addiction, had a partial recurrence of pain at three years. She was nevertheless able to practise medicine up to the day of her fatal infarction nearly eight years after operation. Patient 17B has recently written: "I am really a new man. That is, the great relief from pain that finally resulted from the operation has enabled me to carry on at home and in business, adjusted to a slower tempo—but, by and large, quite fully able to participate in all activities short of athletics." This has been confirmed by his physician, Dr. Arthur DeGraff of New York. *On the whole the results of the recent operations have been so satisfactory that we are planning to use thoracic sympathetic ganglionectomy as preferable to alcohol injection in all but the worst risk cases. It is evident that every precaution must be taken to prevent nerve regeneration and that the operation does not eliminate occasional residual pain referred to the jaw. This does not appear to be a serious problem but can, if necessary, be relieved by trigeminal injection.*

c. Results of posterior rhizotomy:—This operation, as stated above, requires a more extensive removal of bone and a longer period under anaesthesia than simple resection of the ganglia. It should be reserved for the best risk cases with bilateral pain. For one-sided pain ganglionectomy is preferable. Laminectomy and posterior root section must necessarily re-

TABLE XLVII

RELIEF OF PAIN IN SEVERE ANGINA PECTORIS BY POSTERIOR RHIZOTOMY T1-T4 OR T5

Surgeon	*Cases*	*Deaths*	*Results*
L. Davis (Chicago)	1	0	Complete relief at 4 yrs.
W. V. Cone (Montreal)	1	0	Complete relief.
F. C. Grant (Philadelphia)	5	1	Residual subclavian pain in 1.
H Haven (Seattle)	5	1	Complete relief at 4 to 10 yrs.
W. G Crutchfield (Charlottesville)	6	0	Complete relief.
B. S Ray (New York)	11	1	Complete relief up to 9 yrs.
Massachusetts General Hospital	1	0	Complete relief to death at 2 yrs.

Only the cases of Davis (1933), Haven (1942), and Ray (1943) have been published; the others have been reported to the authors by the surgeons listed above and Ray has given us a report on 5 additional cases.

main the procedure of choice for the small group of modern neurosurgeons who are not experienced in the technique of sympathectomy. It is also a valuable recourse in those rare cases where paravertebral alcohol injection has failed to afford a satisfactory degree of relief or has been followed by a disagreeable neuralgia. Statistics are summarized in Table XLVII. These results demonstrate the effectiveness of the method, as only a single patient had any residual pain. The postoperative mortality has not been high.

The following case history is of special interest, as it illustrates the benefit of freeing a patient of crippling pain from the point of view of his own peace of mind and restoration to active work over a period of more than 12 years. We had felt that this doctor was a good risk for thoracic ganglionectomy and had therefore recommended this procedure. Against our better judgment, but at his own request, a paravertebral injection of alcohol was carried out. Cardiac nerve block with alcohol relieved his left-sided pain, but was marred by an unusually severe intercostal neuralgia. Subsequent bilateral posterior root section performed by Dr. Bronson Ray in New York cleared up his neuralgia, which had almost subsided, and put an end to the less severe attacks of pain on his right side. It is of interest to observe that this patient, as has been the case with some of those treated by thoracic ganglionectomy, has developed a slight residual pain in the jaw. We are including this interesting case history with the patient's and Dr. Ray's kind permission.

Patient 73A, Dr. N. L., MGH U-343743BM, 51. Arteriosclerotic heart disease with coronary occlusion.

This prominent physician was referred to us by Dr. David Barr of New York. He was a man of outstanding physical and mental energy, who had developed mild substernal oppression in 1929. In spite of this he had continued under-water swimming, skiing, and mountain climbing, as well as carrying on a strenuous practice of medicine. In the spring of 1941 he suffered a mild coronary infarction. From then on he did not slacken his work, but took from 8 to 20 nitroglycerine tablets a day with large doses of aminophyllin, and suffered pain on less exertion. On arrival in Boston he was exhausted and having up to eight attacks by day and five by night, associated with dreams that the ship in which he arrived was being attacked by submarines or that he was about to miss the boat and having to run for it. He experienced pain on both sides of the precordium, with occasional radiation to the right as well as the left arm. Physical examination showed a stocky and well-muscled man of middle age without cardiac enlargement or murmur. There was no dyspnoea or other evidence of cardiac failure and his electrocardiogram gave no evidence of recent myocardial infarction. Blood pressure was recorded at 130/80. The Wasserman reaction was negative, and x-ray revealed no evidence of gall bladder disease, but he had a small hiatus hernia. It was the opinion of the medical consultants that this was not the cause of his pain.

Because of his good general condition surgical denervation of the heart was recommended in preference to injection of alcohol, but the patient elected the latter. Paravertebral injection of procaine followed by alcohol was carried out on the left side on 3/10/42. The early results were excellent, as the patient had little discomfort and was relieved of all his anginal pain, but three weeks later, while recuperating at the New York Hospital, he de-

veloped a severe neuralgia in the left chest. With this he noticed a return of anginal pain on the uninjected right side. Two months later this was subsiding when Dr. Bronson Ray carried out a bilateral section of the upper four thoracic posterior spinal roots. After this all vestiges of intercostal irritation disappeared, as well as his residual right-sided angina. He continued to observe an adequate warning signal on over-exertion, which consisted of a sense of painless constriction under his upper sternum. He then returned to his home and to his medical work.

The excellent all-around result which followed radical surgery has continued. In a letter written in June, 1946, he stated that he never at any time experienced pain in his chest. There was only a mild sense of constriction there and also a sense of mild pain referred to his jaw. Fortunately it always went away with nitroglycerine and, as it prevented over-activity, he felt that it had a beneficial value. His electrocardiogram then showed a low T-wave in the first lead and the presence of ventricular premature beats. He stated that he was accustomed to leave his house for the hospital at eight in the morning and usually got back around six, with an occasional afternoon off. "At present I am on the Governor's Hospital Study Commission and the Statehood Committee. I have just finished as president of the County Medical Society and am involved with the . . . dentists on a study of dental decay in relation to diet. Of course, in a business and professional way I am interested in a number of other things, but they are part of work." His last letter, 11 and three-quarters years after operation, reported his continuance of medical practice and freedom from painful attacks.

A very similar case (*Patient 1C,* Frank A., MGH U-220541BM) was operated upon at the Massachusetts General Hospital in 1948 with most satisfactory results. The area of anaesthesia following posterior rhizotomy from T1 to T4 inclusive is shown in Figure 128. His warning signal also consisted of a mild sensation, not true pain, in his jaw and a painless sense of constriction beneath his sternum. He remained free of his formerly unbearable anginal attacks and carried on a large roofing business until the day of his death. This took place two and a half years after his operation, when he suffered a sudden fatal coronary thrombosis, in which the only pain he experienced was referred to the jaw. The diagnosis was confirmed by post-mortem examination.

In summarizing experiences with the neurosurgical treatment of medically intractable cardiac pain, we wish to stress that *resection of the upper thoracic ganglia or section of the corresponding spinal sensory roots is preferable to paravertebral injection of alcohol, provided the patient can tolerate a major operative procedure. These two operations rarely cause neuralgia, and abolition of cardiac pain is reasonably certain. On reviewing the earlier cases treated by paravertebral injection, we find that the risk of operation would have been too serious in about half of the series.* These

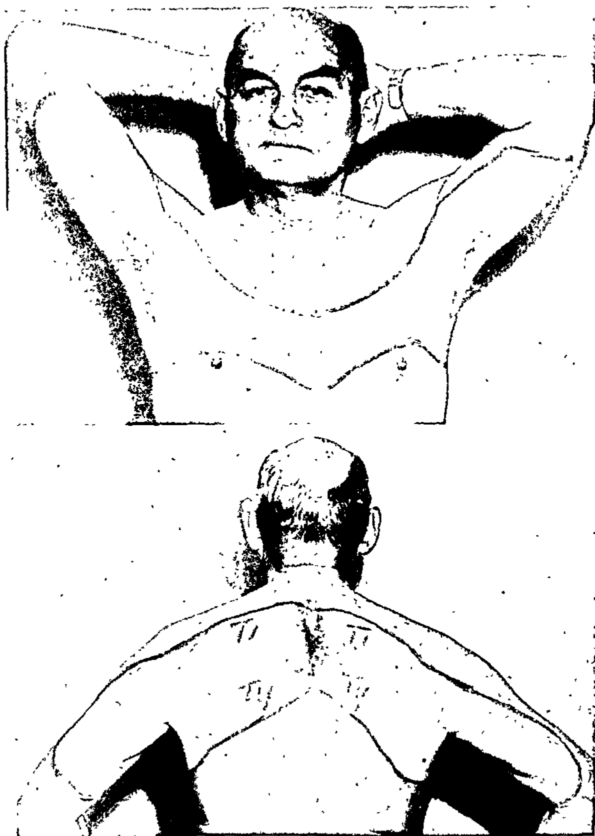


Fig. 128. Extent of anaesthesia after posterior rhizotomy T1 to T4.

Bilateral anginal pain was relieved in Patient 1C until he died of a coronary occlusion two and a half years later. In his fatal attack he experienced only mild pain referred to his jaw. This man had returned to work as a roofing contractor. A sense of constriction beneath his upper sternum and slight pain in the lower jaw gave him an effective warning whenever he attempted to undertake too much.

patients had had recent or multiple coronary infarctions, were decompensated, had active rheumatic heart disease, or syphilitic aortitis. *For such advanced cases of cardiac disease paravertebral block still must be the surgical procedure of choice*, but many can now be more safely treated by inducing hypothyroidism with radioactive I^{131} (see p. 618).

Provided the immediate complications of acute myocardial infarction or congestive failure are successfully avoided, it is fair to conclude that only good results have followed surgical intervention. Mackenzie's (1924) fear that removal of the warning signal of pain would permit the individual to damage his heart by over-exertion has not been substantiated, because the sense of painless constriction and dyspnoea have been effective deterrents. Daniélopolu (1919) formerly argued that removal of the stellate ganglion was fraught with serious danger to the heart, but evidence for this has also been lacking. Indeed, relief from pain and mental anxiety are most effective therapeutic agents. This has been particularly apparent in Patients 6B, 8B, 1A, 35A, 39A, 51A, 61A, and 73A, all patients with totally incapacitating angina decubitus who were requiring morphine for relief. The hopeless mental outlook, with drug addiction either threatening or already present, and exhaustion from lack of sleep appeared to limit the period of life expectancy to but a few months. These patients, with the exception of one (39A) who died at 10 months after injection following an ill-advised operation on his gall bladder, have survived for periods of from three to nine years. After 11, six and a half, and eight years respectively, Patients 51A, 73A, and 7B still continued to lead active and useful lives. The present examination of the heart and the electrocardiograms in two of these patients now show relatively little evidence of coronary disease.

Tables XLV and XLVI include the data necessary to evaluate the eventual outcome in those patients who obtained lasting remission of cardiac pain. From these statistics alone *it cannot be concluded that life is definitely prolonged, except in the group described above where angina decubitus and exhaustion from constant fear, loss of sleep, and morphine addiction seemed to be rapidly pushing the patient to a fatal termination of his disease. Nevertheless, the deliverance from long periods of chronic suffering and, furthermore, the frequently painless character of even fatal attacks of coronary thrombosis are most effective arguments for the wider use of surgery in this disease.*

B. AORTIC ANEURYSM

Syphilitic aneurysm of the arch and descending aorta may give rise to excruciating pain. These patients often cannot be benefited by antiluetic

treatment and are not suitable for wiring or other direct surgical procedures. Mere palliation of this agonizing pain gives the greatest comfort to these sufferers, as first demonstrated by White (1932) in a report of three successful cases. This was later corroborated by Dr. F. L. Reichert (personal communication) and a recent additional case at the Massachusetts General Hospital. Most aortic aneurysms are not actually painful, although they may be the cause of considerable distress from compression of the trachea and oesophagus. The exact cause of pain from this condition is not known with certainty. If it is due to a stretching of the wall of the sac and its intrinsic nerves, the pain should be transmitted over the upper thoracic sympathetic fibres. On the other hand, if caused by erosion of the sternum or vertebrae or compression of other structures at the apex of the chest, it would more likely result from irritation of intercostal nerves.

When we were first confronted by this problem there was no available information to help in the selection of a palliative neurosurgical procedure. The first case is of such interest that it is best to report it in some detail.*

Patient 1, James B., Old MGH #275444, 48, a native American railroad conductor, contracted a penile chancre in 1901. He had no treatment until 1926, when he first noted pain in his right shoulder and dyspnoea on exertion. A Wassermann test of the blood was then strongly positive. Physical examination showed his heart to be enlarged to the left and downward. There was a loud systolic murmur at the base, transmitted into his neck, as well as loud systolic and diastolic murmurs at the apex. The ascending aorta was expanded into a large aneurysm, with some dilatation of the innominate artery as well.

Subsequent to this he was treated in the medical out-patient department. He found lighter work as a railroad clerk and felt well until June, 1929. He then began to be troubled by palpitation on exertion and periods of syncope. Three weeks before his admission in January, 1930, he caught cold and developed a dry, hacking cough. A week later he began to suffer extremely from a pain behind his right ear, running down his neck over the right shoulder and upper part of the chest. This pain was constant and burning in character and became intolerably severe when he coughed. His cough became dry, nonproductive, and brassy.

The patient was obese, with a cyanotic, swollen face. There was a bulging, pulsating tumour rising above the right side of the manubrium and the medial half of the clavicle. The right radial pulse was greatly diminished, and blood pressure reading on the two sides showed a pressure of 85/70 on the right and 115/80 on the left. The Wassermann and Hinton tests of the blood continued strongly positive. Roentgen examination showed a

*White, J C.: Painful aneurysms of the aortic arch: Relief by paravertebral injections of procaine and alcohol, *J. Amer. Med. Asso*, Chicago, 99 10-13, 1932.

great increase in the size of the aneurysm, which now involved the entire ascending aorta and the beginning of the great vessels.

Antisyphilitic measures having been pushed to the limit without relief, it was essential to do something to palliate the pain. The wide area over which this pain was referred included both the upper cervical and upper thoracic spinal segments. As there were no previous reports in the literature, it was necessary to determine in the first place whether the painful impulses were transmitted over the cervical and upper dorsal spinal nerves, or whether they entered the cord through the sympathetic rami. In the former case, laminectomy and section of multiple posterior roots would have been necessary, a procedure which the patient might not have tolerated. On the other hand, if the pain traversed the sympathetic nerves, sensory axones would pass through the upper thoracic ganglia.

On February 7, 1930, a diagnostic blocking of the first and second thoracic sympathetic ganglia clearly proved the latter to be the case by relieving the pain for 36 hours. Five cc. of 95 per cent alcohol were then injected paravertebrally into each of these areas. This produced a small band of anaesthesia reaching across the upper part of the back into the axilla, which disappeared in two weeks. There were no troublesome sequelae. The patient was relieved of all his pain and was discharged two weeks later.

He remained free from pain for four months. He then re-entered the hospital decompensated and died suddenly of rupture of his aneurysm. An autopsy was performed and showed a huge aortic aneurysm, which had ruptured anteriorly. Examination showed two small retropleural scars about 1.5 cm. in diameter. These surrounded the first and second intercostal nerves at their point of emergence from the intervertebral foramina, their communicant rami, and the corresponding sympathetic ganglia.

Diagnostic paravertebral block with procaine was of the greatest possible assistance in this case, as the pain was referred over such a large number of cutaneous dermatomes and yet could be relieved by procaine infiltration of only the upper two thoracic ganglia and their communicant rami. The injection of alcohol was therefore limited to these two segments.

Paravertebral block of these ganglia was equally successful in the next two cases, which are summarized in Table XLVIII. These involved the transverse and descending arch of the aorta respectively, with erosion of the sternum in each. In these the pain was entirely left-sided, whereas in Patient 1 with disease of the ascending arch it was referred entirely to the right. In Reichert's case and in our Patient 4, where one of the two aneurysms was in the descending arch, the pain was left-sided and referred to somewhat lower segments.

These patients were far from good surgical risks. Even had we dared expose the upper thoracic sympathetic ganglia by either the anterior or posterior approach, any manipulation in this area might well have ended

treatment and are not suitable for wiring or other direct surgical procedures. Mere palliation of this agonizing pain gives the greatest comfort to these sufferers, as first demonstrated by White (1932) in a report of three successful cases. This was later corroborated by Dr. F. L. Reichert (personal communication) and a recent additional case at the Massachusetts General Hospital. Most aortic aneurysms are not actually painful, although they may be the cause of considerable distress from compression of the trachea and oesophagus. The exact cause of pain from this condition is not known with certainty. If it is due to a stretching of the wall of the sac and its intrinsic nerves, the pain should be transmitted over the upper thoracic sympathetic fibres. On the other hand, if caused by erosion of the sternum or vertebrae or compression of other structures at the apex of the chest, it would more likely result from irritation of intercostal nerves.

When we were first confronted by this problem there was no available information to help in the selection of a palliative neurosurgical procedure. The first case is of such interest that it is best to report it in some detail.*

Patient 1, James B., Old MGH #275444, 48, a native American railroad conductor, contracted a penile chancre in 1901. He had no treatment until 1926, when he first noted pain in his right shoulder and dyspnoea on exertion. A Wassermann test of the blood was then strongly positive. Physical examination showed his heart to be enlarged to the left and downward. There was a loud systolic murmur at the base, transmitted into his neck, as well as loud systolic and diastolic murmurs at the apex. The ascending aorta was expanded into a large aneurysm, with some dilatation of the innominate artery as well.

Subsequent to this he was treated in the medical out-patient department. He found lighter work as a railroad clerk and felt well until June, 1929. He then began to be troubled by palpitation on exertion and periods of syncope. Three weeks before his admission in January, 1930, he caught cold and developed a dry, hacking cough. A week later he began to suffer extremely from a pain behind his right ear, running down his neck over the right shoulder and upper part of the chest. This pain was constant and burning in character and became intolerably severe when he coughed. His cough became dry, nonproductive, and brassy.

The patient was obese, with a cyanotic, swollen face. There was a bulging, pulsating tumour rising above the right side of the manubrium and the medial half of the clavicle. The right radial pulse was greatly diminished, and blood pressure reading on the two sides showed a pressure of 85/70 on the right and 115/80 on the left. The Wassermann and Hinton tests of the blood continued strongly positive. Roentgen examination showed a

*White, J.C.: Painful aneurysms of the aortic arch: Relief by paravertebral injections of procaine and alcohol, *J. Amer. Med. Asso.*, Chicago, 99.10-13, 1932.

fatally from rupture of the aneurysm. In Patient 4 there was such acute tenderness of the upper half of the thorax on the left side that we elected to perform the more extensive procedure of laminectomizing seven vertebrae and cutting eight posterior spinal roots in two stages. This patient would have been an impossible surgical risk at the time of the previous report 22 years ago, but with more modern techniques including intratracheal anaesthesia and the lateral instead of the prone position during operation she was carried through the procedure uneventfully, despite her partial oesophageal and tracheal obstruction. Her case history is summarized below:

Patient 4, Mrs. Gertrude T., MGH U-627624, 67, was admitted in July, 1948, with the complaint of left upper thoracic pain. In addition to continuous discomfort in this area for the past six months, she had suffered episodes of excruciatingly severe distress which were occurring with increasing frequency. Prior to the onset of pain she had noticed a foul taste in her mouth for over a year, with periods of coughing followed by expectoration of foul mucus. At times she also had difficulty in swallowing and felt as though she might choke. She had never known that she had syphilis, but recalled a small painless ulcer on her vulva 15 years previously, which had healed with local treatment.

Examination showed a pale, somewhat emaciated woman with extreme tenderness over the upper thorax on the left side and a forceful pulsation in the region of the heart, which was not enlarged. No murmur was heard. The pulse was regular, blood pressure was 112/70. The blood Hinton was strongly positive. The striking x-rays of her chest are shown in Figure 129A.

She was seen in consultation by Dr. R. R. Linton of the peripheral vascular clinic, who felt that no direct surgical attack on the two large aneurysms was possible. The patient, however, had such severe pain that she was referred to the neurosurgical service. She was then taking 75 mgm. of Demerol several times a day and was unable to sit up even in bed because of her discomfort. In her severe attacks she complained of throbbing pain in the left chest synchronous with the heartbeat. She doubled up in bed and grasped her left breast in both hands. The face and neck were then cyanosed and she was drenched with sweat.

Because of the extreme tenderness of her left upper thorax and because she had no evidence of aortitis, coronary disease, or decompensation, we decided that posterior rhizotomy would give her the best chance for effective relief without too great risk. This operation was performed in two stages, with removal of seven thoracic laminae and section of the eight upper thoracic sensory roots on the left side. The two stages were carried out 17 days apart, under intratracheal ether anaesthesia with the patient in the right lateral position. Recovery from each was uneventful and relief of pain complete. A month later she was able to be up and about without discomfort, although she still had symptoms suggestive of intermittent

Table XLVIII

PAIN IN AORTIC ANEURYSM

Patient	*Age*	*History and Physical Findings*	*Area of Pain*	*Surgical Treatment*	*Result*
1 James B. Old MGH #275444	48	Chancre in 1901. No treatment prior to aortitis in 1926 Wassermann + + +. Aneurysm of ascending aortic arch and aortic regurgitation.	Pain to R. occiput, neck, and upper thorax, severe and resistant to antiluetic therapy.	1) Diagnostic paravertebral procaine block T1 and T2 (R) 2) Paravertebral alcohol injection, 2/7/29.	Complete relief for 36 hrs. Complete relief to death 4 mos. later from rupture of aneurysm.
2. Antonio C. Old MGH #309403	54	Penile sore at 18, untreated 7 mos. cough with accompanying pain Pulsating swelling L. upper chest and Horner's sign. Wassermann +++. X-ray evidence of aneurysm of transverse arch with sternal erosion.	Inner L. arm, scapula, and neck of increasing severity, unrelieved by antiluetic therapy or 15 mg. morphine q 3 hrs.	Paravertebral procaine block at T1 and T2 (L), 10/22/30.	Complete relief for 3 wks. He then had partial return of pain for which he was to be readmitted for alcohol injection. This subsided spontaneously and he died painlessly of sudden haemorrhage following a coughing spell 2½ mos. later.
3 Eric S. Old MGH #272915	37	Penile chancre in 1913 with only local treatment. First hospital admission in 1925: Wassermann +++, antiluetic treatment started. Two wks *before second* admission lump developed in sternum with severe pain and hyperaesthesia. X-ray showed pulsating aneurysm of descending arch of aorta, sternal erosion, greatly enlarged heart.	Pain in L. clavicle and upper anterior thorax with hyperaesthesia of this area *and great tender*ness over mass in manubrium sterni.	Paravertebral procaine-alcohol block T1 and T2 (L), 12/4/30.	When seen on frequent occasions complained of no further pain, although unable to work because of residual dyspnoea and fatiguability. Death from tracheal compression after 5½ yrs.
4. Gertrude T. MGH U-627624	67	Untreated chancre 1925. Coughing up foul mucus for 1 yr. with pain L. upper chest for 6 mos. Two aneurysms in descending arch and lower thoracic aorta.	Constant hyperaesthesia and pain L. upper thorax with episodes of excruciating severity.	1) Posterior rhizotomy T4-T8, 8/13/48. 2) Posterior rhizotomy T1-T3, 9/1/48.	Remained free of pain for ensuing 6 mos. of life. Death occurred suddenly and painlessly on 3/15/49 from rupture of aorta.

of procaine alone gave sufficient relief over the two and a half months' period of survival. In Patient 4 there was so much tenderness of the thoracic wall, presumably mediated over intercostal nerves, that rhizotomy appeared to be the operation of choice. We have, however, seen corresponding degrees of tenderness in cases of pancreatic fibrosis and nephralgia disappear after sympathetic denervation, and would not have been surprised if this had occurred following chemical sympathectomy in this patient.



ief of pain by section of upper right posterior
of cutaneous anaesthesia is outlined.

persistent pain in aneurysms of the ab-
ng pain of dissecting aneurysm is rarely
long continued it could doubtless be
If syphilitic aortitis with aneurysm
should ever result in unbearable
stigated by procaine block and
information.

bronchial and oesophageal obstruction. The distribution of chest wall anaesthesia is shown in Figure 129B.

From our experience we are convinced that *intractable pain in thoracic aneurysms can be effectively relieved by chemical block of the regional*



Fig. 129. Aneurysm of the aorta.
A. X-ray of Patient 4, Table XLVIII, with double aneurysms in descending arch and midthoracic portion of descending aorta brought out by barium in the oesophagus.

paravertebral sympathetic ganglia or by section of the appropriate spinal sensory roots. Where the pain is spread over such a wide area as in Patient 1 and can be abolished by procaine injection limited to only two ganglia, an attempt to block them permanently by alcohol is obviously the method of choice. This was equally true of Patient 3. In Patient 2 injection

of procaine alone gave sufficient relief over the two and a half months' period of survival. In Patient 4 there was so much tenderness of the thoracic wall, presumably mediated over intercostal nerves, that rhizotomy appeared to be the operation of choice. We have, however, seen corresponding degrees of tenderness in cases of pancreatic fibrosis and nephralgia disappear after sympathetic denervation, and would not have been surprised if this had occurred following chemical sympathectomy in this patient.



B. Patient 4 after relief of pain by section of upper right posterior roots. The extent of cutaneous anaesthesia is outlined.

We have never encountered persistent pain in aneurysms of the abdominal aorta. The acute agonizing pain of dissecting aneurysm is rarely a neurosurgical problem, though if long continued it could doubtless be relieved by paravertebral injection. If syphilitic aortitis with aneurysm of the lumbar aorta or its bifurcation should ever result in unbearable chronic pain, its pathways should be investigated by procaine block and an appropriate procedure devised from this information.

C. LUNG

The parenchyma of the lung and its visceral pleura, like the brain, appears to be insensitive to pain (White, 1943). Pulmonary disease, of either inflammatory or neoplastic origin, is therefore painless until it has spread to the parietal pleura or involved the main bronchi and trachea. The pain evoked by disease of these structures is not transmitted over

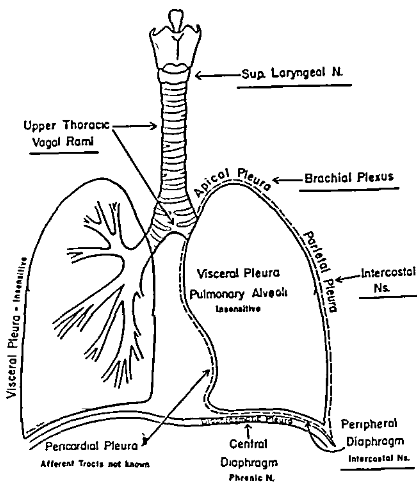


Fig. 130. Sensory innervation of the trachea, lungs, and bronchi. From White: *Research Publ. A. Nerv. & Ment. Dis.*, 1943. Courtesy, The Williams and Wilkins Co., Baltimore.

visceral afferent fibres in the sympathetic system. In the case of the parietal and diaphragmatic pleura it is transmitted by the intercostal and phrenic nerves (Fig. 130). Relief therefore cannot be obtained by sympathetic denervation, but requires section of the posterior roots or spinothalamic tract. Examples of this are given in Chapter XVIII. On the other hand, when the trachea or main bronchi are invaded by bronchogenic carcinoma, Morton *et al.* (1950) have found that the disabling pain and irritative cough can be relieved by sectioning the homolateral vagus just beneath

its recurrent laryngeal branch. This observation has been made after 30 operations with adequate postoperative follow-up studies in 18. More recently Morton *et al.* (1951) have stimulated the mucosa of the main bronchi by means of electrodes inserted through a bronchoscope. When this is done after unilateral vagotomy just below the recurrent laryngeal nerve, no pain is evoked on the denervated side, but similar stimulation on the control side with intact vagal innervation causes the subject to complain of pain in the ipsilateral anterior chest and neck.

CHAPTER XX

PAIN IN ABDOMINAL VISCERAL DISEASE

A. GASTROINTESTINAL TRACT

1. Oesophagus

THE LOWER PORTION OF THE OESOPHAGUS receives its sensory innervation via fine rami from the splanchnic nerves and paravertebral ganglia (Fig. 131). Jones and Chapman (1942) and more recent unpublished observations of Chapman in the Massachusetts General Hospital have shown that after the most extensive thoracic sympathectomies experimental distension begins to cause distress when the balloon is drawn above the sternoclavicular joint. Distension above this level causes pain even in the presence of spinal anaesthesia carried above the first thoracic segment and after transection injuries of the cord as high as the fifth cervical vertebra. Grimson, Hesser, and Kitchin (1947) have observed that stimulation of the vagi in patients under spinal anaesthesia, while not painful at the diaphragm, causes a sensation of "heartburn" as well as pain referred to the neck when performed 3 inches above this level. It is therefore probable that pain arising in the upper thoracic and cervical oesophagus is transmitted by sensory fibres in the vagi, as has been shown to be the case with the trachea and bronchi in bronchogenic carcinoma where disabling symptoms of pain and cough have been palliated by section of the homolateral vagus nerve below the origin of its recurrent laryngeal branch (Morton, Klassen, and Curtis, 1950).

Because of this anatomical arrangement sympathectomy, rhizotomy, and cordotomy are all likely to fail to relieve pain arising from lesions in the upper oesophagus. With their added difficulties in swallowing food and at times even their own saliva, these patients are victims of much emotional as well as physical distress. As bilateral vagectomy at this level would paralyze both vocal cords, frontal leucotomy appears to be the only solution for pain in malignant disease of the cervical oesophagus.

2. Stomach and Duodenum

It is most unlikely that the vagi carry any sensation from the abdominal viscera (see p. 81). The fact that ulcer pain so often disappears after vagotomy is accounted for by the reduction in acid secretion and peristalsis, not by the interruption of axones conducting pain.

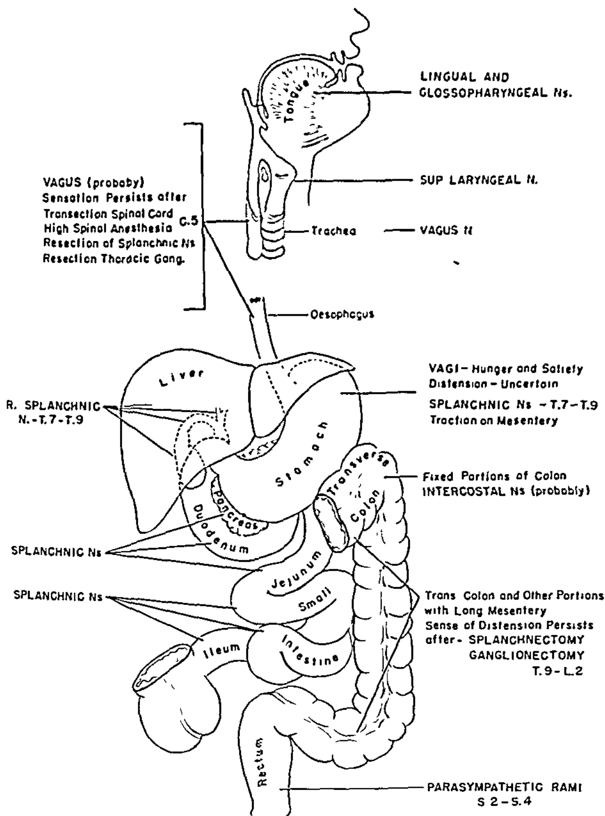


Fig. 131. Sensory innervation of gastrointestinal tract.

Gastroduodenal pain is transmitted over afferent fibres in the splanchnic trunks (Balchum and Weaver, 1943; Herrin and Meek, 1945) which enter the spinal cord predominantly at the seventh and eighth thoracic segments (Läwen, 1923). This splanchnic transmission has been demonstrated dramatically in man at the time of operation for duodenal ulcer under abdominal field block anaesthesia by Bentley (1948B). He observed that deep palpation through the abdominal wall was still painful and that the patient complained of similar pain when the exposed ulcer was directly pressed upon or transfixed with a needle, while after direct injection of the splanchnic nerves with procaine all discomfort disappeared. Bentley and Smithwick (1940) had previously shown that balloon distension of the duodenum was no longer painful after sympathectomy for hypertension. In White, Smithwick, and Simeone's (1952) book there are reports of two cases with persistent pain from chronic duodenal ulcers which were eroding posteriorly in the region of the pancreas. Hypertensive heart disease with angina pectoris made direct surgical intervention impossible, but Smithwick was able to relieve the pain by paravertebral injection of alcohol against the lateral surfaces of the fifth to seventh thoracic vertebrae on the right side. However, it should be pointed out that splanchnic block as a treatment in peptic ulceration is justifiable only in patients who are such poor risks that neither resection nor vagotomy can be considered. Under these unusual circumstances the procedure may be undertaken as a calculated risk. Pain in gastric carcinoma, however, requires anterolateral cordotomy for its interruption, as the sensation is transmitted by somatic nerves from invaded structures in the posterior abdominal wall.

3. Lower Gastrointestinal Tract

Investigation of intestinal sensitivity to distension by Bentley and Smithwick (1940) has demonstrated that discomfort from inflation of balloons in the jejunum is abolished by splanchnicectomy and the standard thoracolumbar ganglionectomy performed for hypertension. Distension of the colon, however, still causes discomfort. This is no longer felt after injuries to the lower caudal roots, proving that the colonic afferent axones run in the sacral nerves, as is the case with the bladder. These are carried by a ramus from the sacral plexus and hypogastric ganglia, which runs up along the descending colon (G. A. G. Mitchell, 1935A).

Troublesome pain may develop as a complication of abdominal surgery due to adhesive bands and kinks in the small intestine or to areas of local distension with abnormal peristalsis. Unless there is actual mechanical obstruction, relief of pain from intestinal distension and dyskinesia (disordered peristaltic activity) may be achieved by splanchnicectomy. One

of the first cases to be successfully relieved was operated upon by Smithwick and is described in his monograph with White (1941). A series of patients with persistent postoperative painful adhesions has since been operated upon by various surgeons of the Massachusetts General Hospital staff and described by Sarnoff, Arrowood, and Chapman (1948). Preliminary testing with procaine by either selective subarachnoid or paravertebral splanchnic block has made it possible to convince the patient as well as the referring surgeon of the benefits of the proposed sympathectomy. Inasmuch as the supradiaphragmatic operation performed through the eleventh rib approach of Peet (see p. 353) permits a bilateral splanchnicectomy and resection of the lower thoracic ganglia at one stage with almost no risk, we consider it the procedure of choice in patients who have responded well to diagnostic block with procaine.

The results in the patients operated upon at the Massachusetts General Hospital are summarized in Table XLIX. Unnecessarily extensive sympathectomies were carried out in some of these, but there were no major complications. This is a new procedure and the results cannot yet be regarded as permanent because the period over which these patients were followed is relatively short. The early results, however, have been promising and offer hope for a simple solution to a very baffling problem.

In contrast, sympathectomy has nothing to offer in the control of pain from the large intestine, whence the visceral afferent pathway is over the sacral nerves. When carcinoma invades the retroperitoneal structures it compresses somatic fibres from the intercostal nerves or the trunks of the lumbosacral plexus and then requires anterolateral cordotomy for relief. The control of pain in malignant disease of the bowel and rectum following this operation has been most satisfactory (see Table XXXVIII).

B. LIVER AND BILIARY TRACTS

Distension of the liver capsule, gall bladder, cystic and common bile ducts is the common stimulus which produces pain in biliary disease (Zollinger, 1933). The sensory fibres run in the plexuses along the biliary ducts (Womack and Crider, 1947; Alexander, 1940) and are concentrated primarily in the right major splanchnic nerve with central connections to the posterior horn over the seventh and eighth posterior spinal roots. The statement that the major splanchnic nerve is the principal visceral pathway is based on experimental findings of Moore and Singleton (1933), Davis, Pollock, and Stone (1932), and on the clinical evidence cited below. Evidence that the pain traverses the seventh and eighth spinal roots rests on early observations of Läwen (1923) and on personal unpublished observations on two patients with meningiomata at these segments which com-

Gastroduodenal pain is transmitted over afferent fibres in the splanchnic trunks (Balchum and Weaver, 1943; Herrin and Meek, 1945) which enter the spinal cord predominantly at the seventh and eighth thoracic segments (Läwen, 1923). This splanchnic transmission has been demonstrated dramatically in man at the time of operation for duodenal ulcer under abdominal field block anaesthesia by Bentley (1948B). He observed that deep palpation through the abdominal wall was still painful and that the patient complained of similar pain when the exposed ulcer was directly pressed upon or transfixed with a needle, while after direct injection of the splanchnic nerves with procaine all discomfort disappeared. Bentley and Smithwick (1940) had previously shown that balloon distension of the duodenum was no longer painful after sympathectomy for hypertension. In White, Smithwick, and Simeone's (1952) book there are reports of two cases with persistent pain from chronic duodenal ulcers which were eroding posteriorly in the region of the pancreas. Hypertensive heart disease with angina pectoris made direct surgical intervention impossible, but Smithwick was able to relieve the pain by paravertebral injection of alcohol against the lateral surfaces of the fifth to seventh thoracic vertebrae on the right side. However, it should be pointed out that splanchnic block as a treatment in peptic ulceration is justifiable only in patients who are such poor risks that neither resection nor vagotomy can be considered. Under these unusual circumstances the procedure may be undertaken as a calculated risk. Pain in gastric carcinoma, however, requires anterolateral cordotomy for its interruption, as the sensation is transmitted by somatic nerves from invaded structures in the posterior abdominal wall.

3. Lower Gastrointestinal Tract

Investigation of intestinal sensitivity to distension by Bentley and Smithwick (1940) has demonstrated that discomfort from inflation of balloons in the jejunum is abolished by splanchnicectomy and the standard thoracolumbar ganglionectomy performed for hypertension. Distension of the colon, however, still causes discomfort. This is no longer felt after injuries to the lower caudal roots, proving that the colonic afferent axones run in the sacral nerves, as is the case with the bladder. These are carried by a ramus from the sacral plexus and hypogastric ganglia, which runs up along the descending colon (G. A. G. Mitchell, 1935A).

Troublesome pain may develop as a complication of abdominal surgery due to adhesive bands and kinks in the small intestine or to areas of local distension with abnormal peristalsis. Unless there is actual mechanical obstruction, relief of pain from intestinal distension and dyskinesia (disordered peristaltic activity) may be achieved by splanchnicectomy. One

				5/40: L. thoracolumbar sympathectomy. Dr. Smithwick found neuroma in continuity in lower portion of splanchnic nerve with microscopic evidence of regenerated fibres passing dural clip in upper pole of coeliac ganglion.	Freed of abdominal distension, had mild residual discomfort. Then report from another hospital that she had colectomy about 3 yrs. postop., but it is uncertain whether symptoms which led to this were similar to former complaints.
. 'emale	38	After multiple pelvic operations developed recurring *bouts of vomiting and low,* primarily left-sided abdominal pain. Abdominal distension after eating. Partial obstruction 2 weeks.	Exploration for sterility and appendectomy, 1930. Removal tubal pregnancy and uterine suspension, 1937. Removal second ectopic pregnancy, 1941. L. oophorectomy and hysterectomy, 1942. R. oophorectomy, 1942.	Differential spinal block.	Passage of gas and flatus. Abdomen became scaphoid for 2 days, then again distended.
				10/40: L. thoracolumbar sympathectomy	At 11 mos. had regained weight and was working. No further left-sided pain but 2 episodes less severe pain on R. with some distension.

TABLE XLIX

ABDOMINAL PAIN FROM POSTOPERATIVE ADHESIONS

Patient	*Age*	*History and Findings*	*Previous Operations*	*Sympathectomy*	*Result*
1. Sylvia H. B. I. #24906 Dr. R. H. Smithwick	34	Bouts of low abdominal pain with constipation, increased peristalsis, and vomiting.	Four laparotomies without benefit	10/10/39: R thoracolumbar ganglionectomy and splanchnicectomy.	Relief of right-sided pain.
				10/23/39: Similar operation on L.	Relief of former pain over follow-up period of 20 mos.
Cases reported by Sarnoff, Arrowood, and Chapman, 1948. These operations were performed by members of the surgical staff.					
2 Female	38	13-year period of attacks of R abdominal pain with episodes of intestinal obstruction.	Appendectomy 10 yrs. before Lysis of adhesions (2 ops). Ileostomy Cholecystectomy. Exploratory laparotomy (2 ops.). Sacroiliac fusion	10/46. Differential spinal block.	Immediate relief of pain with continued passage of gas and 4-inch reduction in girth of abdomen.
				12/46: R. transthoracic sympathectomy with wide resection of sympathetic trunk and splanchnic nerves.	At 9 mos. patient was working and had gained 11 lbs Two further episodes of pain, purely left-sided.
				11/47: L. thoracolumbar sympathectomy.	No further distension or abdominal symptoms.
3 Female	24	3-year history of constipation, right-sided abdominal pain, nausea and vomiting.	Appendectomy. Lysis of adhesions (3 ops.). Resection adherent loop of intestine.	Complete and differential spinal blocks.	Relief of acute abdominal pain and rigidity.
				R. thoracolumbar sympathectomy.	One subsequent episode of mild abdominal discomfort after 6 mos Working as trained nurse.
4. Female	32	Recurring bouts of intestinal obstruction following appendectomy Morphine addiction, psychoneurosis.	Appendectomy, 1933. 6 laparotomies for lysis of adhesions, sidetracking operations, and resection adherent coils of bowel.	9/45: Bilateral thoracolumbar sympathectomies by resident surgeon.	Recurrence of pain after 6 mos.
				Diagnostic spinal block.	Relief of pain with passage of gas and faeces, 4½-inch reduction in girth of abdomen

performed in New York on 4/25/30. Five cc. of 95 per cent alcohol was infiltrated against the bodies of the six lower thoracic vertebrae on the right side. She had no further pain during the remaining two weeks of her life.

Ordinarily splanchnicectomy under direct vision is far preferable to blind destruction of the biliary afferent fibres by chemical infiltration. The value and effectiveness of limited unilateral sympathectomy by the supradiaphragmatic approach is illustrated by the following case history from White, Smithwick, and Simeone's book (1952):

Helen S., MGH U-88059 BM, 45: This patient of Dr. R. H. Smithwick had had multiple operations for long-standing disease of her gall bladder. These had consisted of: (1) drainage of gall bladder at an outside hospital, (2) cholecystectomy with exploration of common and hepatic ducts, (3) re-exploration of common bile duct for increasingly severe right upper quadrant pain with a tender liver and subclinical jaundice.

A plastic procedure was performed on the stenosed ampulla and the patient sent home with an inlying T tube. As long as the catheter drained she remained free of pain, but her characteristic discomfort recurred as soon as the tube was clamped. It returned with its former severity a few weeks later when the tube came out and the sinus closed. She complained of constant right upper quadrant discomfort and sharp attacks of pain radiating to her scapular region, neck, face, and right arm. As she had no jaundice it was concluded that bile must be entering the duodenum, but under back pressure from the stenosed ampulla of Vater. With the evidence of the effective relief of biliary pain by splanchnic block derived from the foregoing case, it seemed wiser to submit her to a simple sympathetic denervation for relief of pain than to a very difficult re-exploration of the common bile duct.

On 5/2/38 Dr. Smithwick therefore resected the right major and minor splanchnic nerves with a short length of paravertebral chain through Peet's eleventh rib supradiaphragmatic approach. The patient left the hospital 10 days later and has remained free of pain.

Twelve other cases of persistent pain after gall bladder surgery with subsequent splanchnic denervations performed by Dr. R. H. Smithwick have been reported by White, Smithwick, and Simeone (1952) Satisfactory relief was obtained by right splanchnicectomy in six patients for
[illegible] one to seven years. In three others recently operated
[illegible] satisfactory, but the period of follow-up is still too
[illegible] conclusions. In three there were late recur-
[illegible] side, for which a second splanchnic denervation
[illegible] obtained lasting relief, but the other two
[illegible] complaints. One was improved when Dr.
[illegible] between the dilated common duct and the

pressed these roots and produced pain simulating gall bladder disease. One had undergone an unnecessary removal of a normal gall bladder. Ordinarily pain from these structures can be corrected by standard surgical procedures. Womack and Crider (1947), however, claim that from "5 to 20 per cent of patients with characteristic symptoms of cholecystitis, and with the classic pathologic findings at operation, will continue to have their symptoms in varying degrees of severity following cholecystectomy." In secondary operations they found extensive scarring in the periductal plexuses in these patients. Mallet-Guy and Feroldi (1950), in an article devoted to this subject, have reproduced the photomicrograph of a typical amputation neuroma compressed in the scar of the cystic pedicle. Similar painful neuromas have recently been demonstrated in the Massachusetts General Hospital by Dr. A. W. Allen in two patients and the pain persisting after cholecystectomy was relieved by their removal. One patient (MGH U-50334BM) remained in satisfactory condition after being followed two years. Concerning the other there is no late information.

Mallet-Guy (1949), who has studied the problem of postcholecystectomy pain so thoroughly with Bezes (1949), with Feroldi and Micek (1950), and with Blondet and Deslous (1949), claims that the elimination of pain by splanchnicectomy is not as important as the improved drainage of bile. These surgeons in Lyons advocate manometric investigation of the pressure in the common bile duct in every case of secondary laparotomy for disease of the biliary ducts. In cases of hypertension, procaine injection of the vagal fibres will result in a fall of pressure to normal levels if there is no obstruction at the papilla. In these circumstances they claim that resection of the vagal fibres at the lesser curvature of the stomach has given excellent results. In cases of hypotension, equally satisfactory results have followed resection of the right major splanchnic nerve between the diaphragm and coeliac ganglion. These methods have not yet been given a proper trial by surgeons elsewhere.

In cases of persistent pain which has proved resistant to standard surgical procedures, chemical destruction or resection of the splanchnic nerves and lower thoracic ganglia on the right side has been very effective after a satisfactory response to a preliminary diagnostic block with procaine. The two following case histories attest the value of this procedure:

Madeleine O., 52. Our first experience came in 1930 in this woman with recurrent mammary carcinoma and an enormous tender liver, which filled the entire right side of her abdomen. This was a source of constant right-sided pain, and she had the added misfortune of being hypersensitive to all derivatives of morphine. The patient was in the last stage of malignant disease and too poor a risk to permit major surgery. At the request of her physician, Dr. H. R. Geyelin, paravertebral procaine-alcohol block was

in Tables L and LII. In the first three cases there was typical pancreatic fibrosis with calculi, in the others carcinomatous invasion of the gland. Unknown to us, Mallet-Guy with Jeanjean and Servettaz (1945) of Lyon had also proposed denervation of the diseased pancreas, but by a unilateral infradiaphragmatic approach. In two out of our three patients the results were successful insofar as pain was concerned, but in Patient 3 continued vomiting and malnutrition necessitated a later attempt at pancreatectomy at another hospital, which ended in death on the operating table from a tear in the portal vein. Patient 2, in whom the result was very difficult to evaluate, was submitted to an unnecessarily radical transthoracic resection by one of the general surgeons. This led to many complications with such disturbing psychoneurotic changes that his result must be classified as a failure. It is, however, quite possible that in cases of advanced pancreatic disease the inflammatory and fibrotic changes, as in carcinoma, may involve retroperitoneal branches of the intercostal nerves, which are not interrupted by sympathectomy. In this connection Bogle (1949) has reported a case of pancreatic calculosis, unrelieved by sympathectomy, that finally responded to subtotal pancreatectomy. It is also apparent that vomiting and malnutrition may not be benefited by sympathectomy. Vagotomy, tried by Rack and Elkins (1950) in two patients, had no beneficial effect.

Sympathetic denervation must usually be performed on both sides. This can be done at one stage by resection of the central ends of the eleventh ribs, as in Peet's supradiaphragmatic operation for hypertension (see p. 353). By this approach it is easy to remove a three-inch section of the splanchnic nerves and the ganglionic chain from T9 above down through T12 in the crus of the diaphragm.

Mallet-Guy, Jeanjean, and Servettaz (1945) reported five contralateral recurrences after 10 unilateral operations, although illogically they ascribe the cause of residual pain on the undenervated right side in the other five to coexistent disease in the gall bladder. The importance of the right-sided innervation and the tendency of pain to recur on the opposite side are brought out in the following summary of our first experience.

Patient 1, Evelyn D., MGH U-532719, 29: This emotionally unstable woman had suffered from severe pain in her right upper abdomen with radiation around the lower ribs to her back for seven years. She first noticed it six weeks after being kicked in the abdomen by her drunken husband. Since that time she had consulted physicians and psychiatrists in New Orleans, Miami, and other cities on the way north to Boston. During this hegira she had undergone the following series of operations: (1) appendectomy in 1939, (2) operation for "intestinal obstruction" in 1941, (3) cholecystectomy in 1942, at which time a swollen pancreas was first observed; (4) gastroenterostomy at New York Polyclinic Hospital for obstruction in 1944, and

duodenum, but x-rays indicated that stenosis was again taking place and at last accounts it appeared that some further procedure would soon be required. The other woman with recurrent complaints was eventually found to have a penetrating posterior duodenal ulcer. She remained symptom free three years after its resection and, in retrospect, it seems likely that her recurrent pain was caused by involvement of the intercostal nerves in the posterior abdominal wall.

Grimson, Hesser, and Kitchin (1947) have reported three successful results in four patients in whom subdiaphragmatic resection of the splanchnic nerves was carried out at the time of exploratory laparotomy for recurrent postcholecystectomy pain. In a more recent article Shafiroff and Hinton (1950) have advocated local resection of the nerves around the common bile duct. We can see no reason for recommending such a difficult procedure in a secondary operative field, where it is so easy to miss delicate rami and regeneration can so easily take place. As splanchnicectomy above the diaphragm is far easier and safer, it seems to us unquestionably the preferable procedure unless a local re-exploration is necessary.

C. PANCREAS

The sensory fibres to the pancreas are carried in the right and left splanchnic nerves and the coeliac plexuses (Richins, 1945). Clinical evidence, detailed below, shows that sensation from the head of the gland is transmitted mainly in the right splanchnic trunk, from the tail in the left. Afferent impulses, arising either from calculi with secondary low-grade inflammation and fibrosis or malignant disease, may give rise to unbearable pain which is felt across the epigastrium and mid back. This pain comes in waves, presumably from back pressure and distension of the ducts. It is so unbearable that most of our patients were extremely neurotic and addicted to both alcohol and morphine. The malnutrition and suffering of these unfortunate individuals has been well described by Martin and Diez Canseco (1947). In the course of their disease they must look forward to many "years of pain, with only a hope that eventual atrophy of the gland will bring surcease." On account of the accompanying inflammatory changes total pancreatectomy, proposed by Whipple in 1946, is often a dangerous if not impossible procedure to carry out. Eliason and Welty (1948) report a mortality of 18 per cent in cases of direct operation on the pancreas. At the time of Whipple's paper before the American Surgical Association (1946) Smithwick in his discussion made the statement that pancreatic denervation for relief of pain, being a far simpler surgical procedure, might often be the preferable method of treatment.

Our experience with sympathectomy for pancreatic pain is summarized

(5) attempt at radical cure by pancreatectomy at New England Deaconess Hospital by Dr. R. B. Cattell in 1945, which was found impracticable because of extensive adhesions.

On admission to the Massachusetts General Hospital in May, 1946, she had a mass in the region of the pancreas and was tender to palpation in the right upper quadrant and over the lower ribs from front to back. The x-ray



[illegible] pancreas, which were cause of severe pain with addiction to morphine and alcohol (Patient 1, Table L).

(Fig. 132) showed calcified areas the size of buckshot in the head of the pancreas. She was not jaundiced and did not have diabetes. In the past she had observed a greasy appearance of her stools, but these were now normal. Serum amylase and bilirubin were not elevated. The patient was a severe alcoholic and had been on a low vitamin intake. Her tongue was smooth and red, and she had a moderate degree of secondary anaemia. The serum protein, however, was not reduced. In addition to the medical studies those of the psychiatrists revealed an extreme psychoneurotic element. Although reported frigid to men, she had been twice married. She picked her nails continuously, suffered crying spells, and had had many alcoholic bouts. Although at times relieved by sterile hypos, she demanded morphine continuously.

6/7/46: Paravertebral procaine block (T10 to L2 on right) gave complete relief of her pain for two hours.

6/19/46: Right transthoracic splanchnicectomy and ganglionectomy (T6 to T12) by Drs. F. D. Moore and J. C. White.

TABLE L

PAIN IN PANCREATIC FIBROSIS AND LITHIASIS

Patient	*Age*	*History and Findings*	*Previous Operations*	*Sympathetic Denervation*	*Result*
1. Evelyn D. MGH U-532719	29	7 yrs. pain in R.U.Q. and back Tender mass in region of pancreas Visible calcification by x-ray. A psychoneurotic woman severely addicted to morphine and alcohol.	1) Appendectomy. 2) Exploration for intestinal obstruction. 3) Cholecystectomy. 4) Gastroenterostomy 5) Pancreatectomy attempted but found impracticable.	Paravertebral procaine block.	Temporary relief
				6/19/46· Splanchnicectomy and ganglionectomy T6-T12 (R).	Complete relief right-sided pain at 2 yrs. Patient has lesser pain on L.
2. Antonio D. MGH U-20456	54	10 previous admissions for gastric carcinoma, lymphogranuloma, and chronic pancreatitis Attacks of left-sided abdominal pain and vomiting.	1) Gastrectomy 2) Cholecystectomy and choledochostomy.	Paravertebral procaine block.	Temporary relief.
				1/18/47: L. transpleural splanchnicectomy and ganglionectomy T6-L2	Serious postoperative complications following unnecessarily radical denervation. Pneumonia and R upper lobe abscess requiring surgical drainage. Severe pulmonary infarction. He was relieved for 8 mos , then recurrent pain and vomiting
3 Margaret C. MGH U-581592	33	18 mos. severe epigastric pain and diabetes. Diagnosis of pancreatic lithiasis by x-ray and exploratory operation.	1) Exploratory laparotomy at Boston City Hospital. 2) 1946. L. sympathectomy (type uncertain) at B C.H.		Pain relieved on L., but recurred in several mos. on R.
				8/28/47: R splanchnicectomy and ganglionectomy T10-L1 through 12th rib incision.	Much incisional pain and psychoneurosis from morphine addiction Abdominal pain relieved, but 6 mos. later entered B.C.H. complaining of persistent nausea and vomiting with extreme loss of weight. Died from tear in portal vein during attempted resection of pancreas.
4. Ruth S. MGH U-752483BM	47	Recurring bouts of pain in epigastrium and back with fever and vomiting. Diagnosis made by exploratory laparotomy.	1) Cholecystectomy. 2) Exploratory laparotomy with drainage of dilated common bile duct.	10/24/51· Bilateral operation with resection of ganglia T8-L1 and L2 and splanchnic nerves Dr. C. E. Welch.	Symptom free at 1 yr.
5. David W. MGH U-712972PH	54	Recurrent attacks of severe aching epigastric distress with vomiting	Whipple operation with resection of head and body of pancreas by Dr. A. W. Allen.	10/27/52: Bilateral Peet operation with resection of ganglia T8-T12 and splanchnic nerves Dr C. E. Welch.	Symptom free at 16 mos.

TABLE LI

OTHER CASES OF PANCREATIC PAIN SUMMARIZED IN RECENT MEDICAL JOURNALS

Authors	*Condition*	*Operation*	*Result*
1945. Mallet-Guy, Jeanjean, and Servettaz	10 cases of pancreatic fibrosis *with calculi.*	Infradiaphragmatic resection of L. splanchnic nerves	One failure at 3 mos. Others remained relieved on L. side, but 5 had residual attacks on undenervated *R. side.*
1947. de Takats and Walter	2 cases of chronic pancreatitis with lithiasis.	Supradiaphragmatic splanchnicectomy and ganglionectomy T9-T12.	Satisfactory relief for 2 and 6 mos.
1947: Martin and Diez Canseco	1 case of pancreatic fibrosis and lithiasis.	1) Laparotomy and exploration of pancreas. 2) Bilateral supradiaphragmatic splanchnicectomy and ganglionectomy (Dr. Rienhoff).	Excellent result at 10 mos.
1949: Ray and Console	4 cases of chronic calcareous pancreatitis.	Bilateral resection of sympathetic ganglia (T11 to L1 inclusive) with added splanchnicectomy	All successful. Case 1, after right-sided denervation, continued to feel pain on L. side. At subsequent laparotomy direct stimulation of pancreas was painful. Complete relief after L. sympathectomy. Case 2 developed infected pancreatic cyst without pain.
1950 Connolly and Richards	2 cases of chronic relapsing pancreatitis.	Supradiaphragmatic resection (bilateral) of splanchnic nerves and ganglia T8-L1.	Both successful.
1950. de Takats, Walter, and Lasner	5 additional cases of chronic pancreatitis with lithiasis.	Supradiaphragmatic resection of splanchnic nerves and ganglia T9-T12 (bilateral resection in 2)	All successful.
1950. Mallet-Guy and Jaubert de Beaujeu	70 cases of chronic relapsing pancreatitis, for the most part secondary to biliary disease with reduced pressure of bile and reflex in duct of Wirsung.	Subdiaphragmatic resection of 3 cm. of major R. or L. splanchnic nerve.	Good early results in 84 per cent. 1 operative death. In 37 cases followed 1 to 6 yrs. good results were maintained in all but 6. Splanchnicectomy on opposite side was performed in only a single case.
1950: Hurwitz and Gurwitz	6 cases of chronic relapsing pancreatitis.	Supradiaphragmatic unilateral resection of splanchnic nerves and sympathetic ganglia T7-T12.	All successful.
1950: Rack and Elkins	2 cases of chronic relapsing pancreatitis.	Bilateral subdiaphragmatic vagotomy.	Failure.
	3 cases of chronic relapsing pancreatitis	Bilateral sympathectomy and splanchnicectomy by Peet technique.	All successful.

This was followed by immediate relief of her tenderness as well as the pain. Convalescence was uneventful except for her neurotic behaviour. She would not cooperate with the psychiatrists and left the hospital against advice. When finally seen two years later she reported that she had never noticed any further right-sided pain. Less severe discomfort had developed a year after operation on the left side, and her present status was complicated by intense nervousness, epileptic seizures, and, although denied, probable continued dependence on alcohol and narcotics. We were unwilling to consider denervation of the left side of her pancreas until she would agree to a preliminary course of psychotherapy, which she refused. It is unfortunate that a bilateral sympathectomy was not carried out as the initial procedure.

These cases and the reports of Mallet-Guy and Jaubert de Beaujeu (1950),* de Takats, Walter, and Lasner (1950), Ray and Console (1949), and others listed in Table LI demonstrate the value of pancreatic denervation for pancreatic lithiasis and fibrosis. Some of these cases had unnecessarily extensive sympathectomies. Experience has shown that bilateral resection of the splanchnic trunks together with the four lowest thoracic ganglia is a sufficient extent of denervation. Sympathectomy is not as effective in nonmalignant disease of the pancreas as in angina pectoris, chronic renal, or uterine pain because the inflammatory process may extend beyond the capsule of the gland.

Since the pain of abdominal carcinoma rarely becomes distressing until the disease has invaded retroperitoneal structures and their somatic nerves, it is not surprising that sympathectomy is usually a failure in this condition. We have been able to obtain worth-while relief in only two out of four cases of malignant disease of the pancreas, and one of these survived for only two weeks. These are summarized in Table LII. In three further experiences with splanchnicectomy for carcinomatous pain reported by de Takats, Walter, and Lasner (1950) and by Ray and Console (1949) the results were not satisfactory. With the tendency of carcinoma to involve somatic nerves in the posterior abdominal wall by the time that severe pain has appeared, it is undoubtedly better policy to interrupt the pain tracts in the spinal cord. This has recently been carried out in a 61-year-old man (Harry T., MGH U-717146), in whom a previous exploration had shown an extensive mass infiltrating the pancreas two and a half years after gastric resection for carcinoma. A bilateral splanchnicectomy by the Peet technique resulted in no lasting benefit. Neither upper thoracic nor a secondary high cervical cordotomy with hypalgesia on the left side to C3 and analgesia to T10 gave him more than transitory relief. According to his wife, severe

*It is surprising that these surgeons are able to report such good results from a unilateral denervation This was not true in our cases, nor in Case 1 cited by Ray and Console (1949).

epigastric pain, which may well have been felt only on the right side, recurred and required narcotic medication during the last 13 days of his life.

To sum up, it has been established that *persistent pain in otherwise intractable biliary as well as pancreatic disease can be relieved by sympathetic denervation. In the case of the liver and biliary ducts, a right-sided resection of the lower thoracic ganglia and splanchnic nerves through the posterior retropleural eleventh rib approach of Peet will usually suffice. In the case of the pancreas, the operation should be carried out on both sides, as this type of pain, even if unilateral at first, has a way of recurring on the opposite side. When pain is caused by malignant disease it can be* [illegible] *the capsule of the viscus.* [illegible] *)r abdominal wall and the spinal nerves, section of the common pain pathway in the spinothalamic tract alone can give relief. It is also probable that the occasional failure of splanchnicectomy to relieve pain in advanced nonmalignant disease of the pancreas can be explained on a similar basis, as the spread of fibrosis is not necessarily limited by the capsule of the gland. The results, however, are sufficiently encouraging to warrant trial of this relatively simple and harmless procedure before recourse to bilateral anterolateral cordotomy.*

The only occasion for attempting to denervate the upper abdominal viscera beneath the diaphragm is at the time of an exploratory laparotomy. Under these circumstances, when an inoperable biliary or pancreatic lesion is encountered and it is desirable to relieve severe and persistent pain, the surgeon may logically attempt to do so at the same operation. This can be done by division of the gastrohepatic omentum and excision of the plexus of nerves and ganglia which surround the origin of the coeliac axis, together with the short length of splanchnic nerves which are visible beneath the diaphragm. This has been carried out with successful results in three out of four cases of intractable pain following cholecystectomy by Grimson, Hesser, and Kitchin (1947) at the time of secondary exploration.

D. KIDNEY AND URETER

The anatomical arrangement of the renal and ureteral plexuses is well described by Mitchell (1935B) and Wharton (1932). Sensory fibres from the upper ureter as well as the kidney accompany the vessels in the renal pedicle. These pass through the aorticorenal and coeliac ganglia to reach the minor and least splanchnic trunks and the lowest thoracic ganglia with which they are connected (Fig. 133). A few fibres presumably reach the first lumbar ganglia as well. Mitchell emphasizes the fact that no operation limited to stripping of the renal pedicle can be counted on to desensitize

TABLE LII

PAIN IN CARCINOMA OF PANCREAS

Patient	*Age*	*History and Findings*	*Previous Operations*	*Sympathetic Denervation*	*Result*
1. Thomas N. Patient of Dr. H. H. Faxon	56	6 mos epigastric pain with radiation to back. Malnutrition and epigastric mass.	1/48. Exploratory laparotomy revealed inoperable carcinoma of head and body of pancreas.	3/48: Supradiaphragmatic splanchnicectomy and ganglionectomy T9-T11 (R).	In following 6 mos. relieved of severe right-sided pain. Mild residual pain on L. but required no opiates and had gained 5 lbs. in weight.
2 John M. MGH U-605253	56	A month of dull aching epigastric pain, most severe on L Deep epigastric tender mass, pancreatic calculi visible in x-ray.	Exploration of carcinoma of pancreas with cholecystjejunostomy.	1/29/49. L. splanchnicectomy and ganglionectomy T10-L1.	Immediate relief after sympathectomy but recurrent pain within a few weeks.
3 Lewis E. MGH U-584489	44	Following resection of pancreas for carcinoma developed local recurrence and pain in R. upper abdomen and back.	8/47: Whipple resection of adenocarcinoma of pancreas.	4/26/48: Splanchnicectomy and ganglionectomy T9-L1 (L) through 11th rib incision. Poor general condition precluded bilateral one-stage denervation.	Complete relief of left-sided pain. Little pain on R. Died 2 wks. after discharge of untreated diabetic coma.
4. Harry T. MGH U-717146BM	61	Gastrectomy in 1948 for carcinoma. Recurrent pain with loss of 70 lbs. weight in weeks prior to admission. Pain in epigastrium and low back, severe on L. side	9/50. Exploration and biopsy of retroperitoneal mass involving pancreas.	10/19/50. Supradiaphragmatic splanchnicectomy and ganglionectomy (bilateral) T8-T12.	Pain relieved for only a week. Required subsequent right-sided thoracic anterolateral cordotomy. This gave temporary relief but sensory level fell Second cervical cordotomy with relief, but abdominal pain recurred within 2 wks.

reported series of 11 cases by Gunnar Bauer (1939), which were carefully followed for five years or more (1944).

Our three patients are summarized in Table LIII. The symptoms in all pointed to renal or ureteral origin of the pain but, as in Bauer's cases, urological studies had failed to reveal any definite lesion, save the congenital abnormality in Patient 2. All were tested by cystoscopy and distension of the renal pelvis in order to ascertain that the pain was identical to that of upper urinary tract origin, and they were then given paravertebral procaine blocks from T10 to L1 to make sure that their pain would be relieved by denervation. The kidney was first thoroughly explored at operation. *Although no pathological cause for the persistent pain could be established, the results of denervation were very successful and were fully maintained over periods of two to eight years.*

In our more recent operations we have preferred to employ a modification of the thoracolumbar approach for hypertension. Removal of the twelfth rib gives an excellent exposure of the kidney for preliminary exploration and for denervation of its pedicle. Added resection of the first lumbar and three lower thoracic ganglia together with the splanchnic trunks is then easily carried out and makes the chances of nerve regeneration far less likely than if the neurectomy includes only a short length of the renal pedicle. This operation, according to Mitchell's dissections, should denervate the kidney completely. It is of interest in this respect that in Patient 2, where the pedicle of the ectopic kidney was not exposed, the renal pelvis remained insensitive to distension two years later. The following history is reported in some detail to illustrate this procedure:

Patient 3, Katharine G., MGH U-295872 BM, 41, referred by Dr. Richard Chute of the urological staff, had complained for many years of pain in the region of the left kidney. She stated that in 1925 this kidney had been suspended by another surgeon, without any benefit, but the small size and position of the operative scar could not have permitted any such procedure. Nephropexy on the right, however, performed in 1941 by Dr. Chute, had relieved similar complaints on that side. There was constant tenderness in the left upper quadrant and in the costophrenic angle, with frequent bouts of acute pain but no chills, fever, or pyuria. X-rays showed both kidneys in normal position, intravenous and retrograde pyelograms showed only a questionable narrowing in her left lower ureter. Her pain was reproduced by distending the left ureter with saline solution through a No. 12 catheter, and abolished by paravertebral injection of procaine against the sides of the twelfth thoracic and upper two lumbar vertebrae.

On 6/7/48 the left kidney and ureter were widely exposed through a thoracolumbar sympathectomy incision with excision of the twelfth rib. No abnormality was found. A 7.5 cm. length of sympathetic chain was then

the kidney completely. According to Szabo (1948), a few renal fibres from as high as the ninth thoracic segment join the coeliac ganglion via the major splanchnic trunk, but the main level of spinal innervation is from the tenth thoracic to the first lumbar segments.

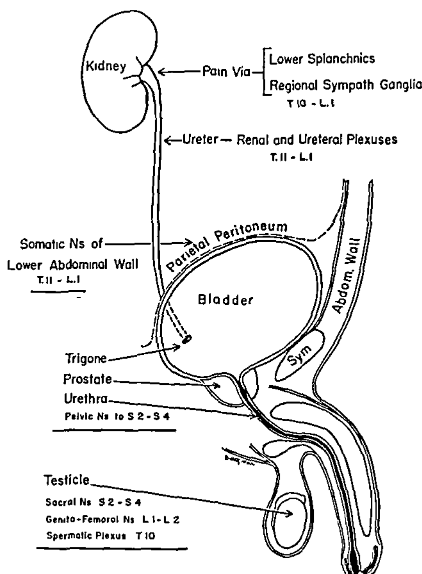


Fig 133 Sensory innervation of kidney, ureters, and male genital tract

From White: *Research Publ. A. Nerv & Ment. Dis*, 1943. Courtesy, The Williams and Wilkins Co., Baltimore.

Total renal denervation causes no obvious change in urinary secretion. Even a limited denervation by stripping the renal pedicle appears to be an effective method of relieving pain originating in the kidney and upper portions of the ureter. Clinical proof for this statement is given by earlier scattered case reports of Hess (1930), Stone (1934), E. L. Peirson and C. L. Deming (see discussion of paper by Stone), and the more recent

resected from the tenth thoracic to the second lumbar ganglia together with the three splanchnic trunks. Recovery was uneventful. Eleven days later Dr. Chute again passed a cystoscope and distended the left ureter with 20 cc. of normal salt solution. She felt no trace of discomfort, although mere insertion of the catheter into her right ureteral orifice was distinctly painful. She noticed no tenderness nor any of her old pain during the two and one-half year period of follow-up.

E. BLADDER AND PROSTATE

The sensory innervation of the bladder, together with the vesical neck and prostate, is over the second, third, and fourth sacral nerves. The sympathetic component of bladder innervation appears to regulate only vasomotor activity and ejaculation, and its stimulation produces slight increase in the tonic contraction of the smooth muscle of the trigone and bladder neck. No reduction of vesical sensibility can be detected after presacral neurectomy, either by filling the bladder or by endovesical stimulation in the course of cystoscopy. On the other hand, after resection of the inferior hypogastric plexus (Learmonth, 1931 A and B), injury to the sacral nerves in the course of pelvic operations, or to their roots (S2 to S4 inclusive) in the cauda equina, there is total loss of bladder sensation as well as motor paralysis. It is therefore impractical to desensitize the bladder by any interruption of its peripheral nerves.

Certain authors have nevertheless reported encouraging results following presacral neurectomy in interstitial and other forms of painful chronic cystitis (Pieri, 1926; Viannay, 1927; Scott and Schroeder, 1938; Learmonth and Braasch, 1933). However, in a more recent publication from the Mayo Clinic, Jacobsen, Braasch, and Love (1944) concluded that "although partial or temporary relief of vesical pain often is observed, permanent relief followed only occasionally, and in this respect the operation has been found wanting." We agree with Nesbit and McLellan (1939) that the occasional favourable effects of sympathectomy are not brought about by interruption of afferent fibres, but by alteration in blood supply and reduction of spasm in the region of the trigone and bladder neck.

From our own restricted experience resection of the superior hypogastric plexus has a very limited value in the treatment of intractable chronic cystitis. As mentioned in White's book with Smithwick and Simeone (1952) two patients reported with interstitial cystitis (Hunner's ulcer) had a reduction in their bladder irritability and pain, but there was no relief of pain in malignant involvement of the bladder. For cases of this sort bilateral section of the spinothalamic tracts is unquestionably the proper neurosurgical procedure. The analgesic level need only be carried to the tenth thoracic seg-

TABLE LIII

PAIN OF RENAL ORIGIN

Patient	*Age*	*History and Findings*	*Previous Operations*	*Denervation*	*Result*
1. Helen C. MGH U-6814 BM	39	Dull aching pain in L. kidney region with bouts of incapacitating severity. X-rays showed spasm of upper ureter. Pain reproduced by distension of renal pelvis	Exploratory laparotomy and salpingectomy for chronic infection.	Paravertebral procaine block T10-L2.	Temporary relief.
				1/5/38: Negative renal exploration, stripping of nerves from renal artery and upper ureter.	Satisfactory relief for 8 yrs
2. Frank S MGH U-168840	32	Congenital single ectopic kidney in R side of pelvis. 14-year history of pain in R. flank and groin. He also had hypertensive and rheumatic heart disease, with severe aortic regurgitation	None.	Diagnostic paravertebral procaine block T11-L1.	
				3/6/44: Thoracolumbar sympathectomy with removal of splanchnic nerves and ganglia T10 to L2.	No further renal pain. Test of ureteral distension 2 yrs. later was painless.
3. Katherine G. MGH U-295872 BM	41	Bilateral renal pain with relief on R. following nephropexy. L costovertebral and abdominal tenderness with bouts of acute pain All urological tests were negative.	1941: R. nephropexy.	Paravertebral procaine block T12-L2.	
				6/7/48: Renal exploration and thoracolumbar sympathectomy with removal of ganglia from T10 to L2 and three splanchnic nerves.	Sympathectomy stopped characteristic pain on distension of renal pelvis. Satisfactory relief over 2½-year period of follow-up

dysmenorrhoea, secondary to pelvic inflammatory disease, endometriosis, etc., other gynecological procedures were carried out in addition to the neurectomy. Results in these were not so satisfactory as relief was complete in only 52.6 per cent, partial in 21, and in 26.4 per cent the operation failed. In their entire series there were only two postoperative complications due to intestinal obstruction in patients with coexistent pelvic inflammation. A single operative complication was encountered when a branch of the left common iliac vein was avulsed, resulting in brief but severe haemorrhage. This was repaired by suturing the rent in the vein with arterial silk.

In discussing their failures Ingersoll and Meigs point out that the greatest handicap for the surgeon is the fact that the cause of dysmenorrhoea remains unknown. It is obvious that these patients are unusually emotional young women with low resistance to pain. The cause of their 12 failures is laid to psychoneurosis (three cases); regeneration of sympathetic nerves, two; and incomplete sympathectomy, seven. It should be possible to rule out the psychoneurotics by preventing ovulation through the use of estrogen and then allowing them to have withdrawal bleeding by stopping the drug. Estrogen withdrawal or anovulatory bleeding should be painless in the normal female. On the other hand, if pain is complained of, it is safe to assume that the patient will experience it in association with any vaginal bleeding. In two patients who had prolonged periods of relief and then recurrent pain at three and seven years after operation, the cause of failure may be accounted for by regeneration. In view of late return of pain after successful relief by sympathectomy in some of our cases of angina pectoris, which took place coincidentally with return of sweating, this seems a logical conclusion. In a case of this sort, Dr. Joseph H. Phillips at the Free Hospital for Women in Brookline, Massachusetts, has recently reoperated and carried out a wider dissection of the interiliac triangle. The successful result is good evidence for regeneration of afferent fibres.

The seven failures ascribed to incomplete denervation were so classified because they continued to have pain without any other explanation. In our description of surgical technique on page 354 it is pointed out that it is easy to miss the rami from the fourth lumbar ganglia which join the superior hypogastric plexus from beneath the iliac vessels. There is also a possibility, as Elaut's (1932) dissections showed, of missing certain fibres which occasionally run in association with the inferior mesenteric vessels and therefore may be retracted so far laterally during the dissection that they are missed.

Ingersoll and Meigs also pointed out that, in contradistinction to low abdominal cramps which come from the uterine fundus, sacral backache may not be relieved because this sensation may be of cervical origin and therefore reach the spine by lower sacral parasympathetic pathways. After

ment and micturition, if still functioning normally, has rarely been seriously impaired (see pp. 245-247).

F. UTERUS

Pain from the body of the uterus is transmitted over the superior hypogastric plexus and pre-aortic nerves. The afferent fibres traverse the paravertebral chains of ganglia for a short distance and are then carried centrally over the lowest thoracic sympathetic rami and posterior spinal roots (Cleland, 1933). Edwards and Hingson (1942) have demonstrated that epidural spinal block will relieve the pain of uterine contractions in the first stage of labour if it is carried up to the eleventh thoracic segment. Sensa-

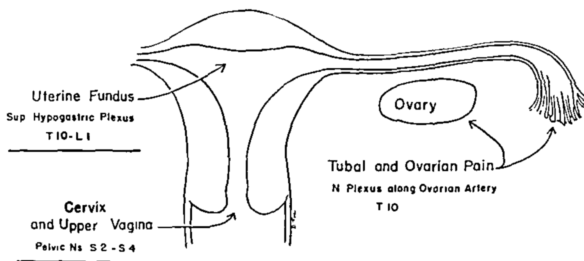


Fig 134. Sensory innervation of female genital tract
From White *Research Publ. A Nerv. & Ment Dis.*, 1943. Courtesy, The Williams and Wilkins Co., Baltimore.

tion from the uterine cervix, on the other hand, is transmitted over sacral parasympathetic fibres to the second, third, and fourth sacral segments. Ovarian pain ascends in the sympathetic plexuses along the ovarian arteries (Fig. 134).

Pain of essential dysmenorrhoea, when severe and failing to respond to ovarian therapy, can be effectively relieved by presacral neurectomy. This operation was first developed by Cotte (1925) and has been popularized in this country by Meigs (1939). In his first series of 20 cases performed in this hospital he deliberately limited the operation to neurectomy of the superior hypogastric plexus. Of these 15 were completely successful, two received considerable benefit, and the remaining three were failures. In his recent report of further experience with 89 cases (Ingersoll and Meigs, 1948), 81 per cent are listed as fully successful, 4.5 per cent as partially so, and 14.5 per cent as failures. In another group of 19 cases with acquired

Such a patient is reported on p. 102, a pharmacist's mate who gave a perfect history of recurrent renal colic and led one of us to denervate his kidney in order to avoid overseas duty in the U. S. Navy.

The following case history illustrates a most successful result:

A 40-year-old patient of Dr. W. J. Mixter began to suffer attacks of right upper quadrant pain immediately following her husband's death. These became increasingly frequent and severe, lasting a half hour or more, and were relieved only by 30 mgm. doses of morphine, to which she was rapidly developing an addiction. General physical and neurological examinations disclosed no abnormality beyond a congenital defect in the disc between T9 and T10 vertebrae. Another surgeon had removed her gall bladder, making her pain considerably worse. This woman was so high-strung and emotional that even the psychiatrists were unable to decide whether her pain was organic or functional in origin.

6/11/29: Injection of procaine against the bodies of T9 to T11 vertebrae on the right side with additional infiltration of alcohol at T10 stopped her painful seizures for six months.

5/6/30: Paravertebral procaine block at T10 in the course of an acute attack gave immediate but temporary relief.

5/8/30: Supradiaphragmatic retropleural resection of right splanchnic nerves and lower thoracic ganglia. Drs. W. J. Mixter and J. C. White.

She had no further attacks of right upper quadrant pain. When seen three years later she had had a brief episode of pain in her lower abdomen and groin, following the death of her daughter, who was burned to death in an airplane accident. This pain was never felt over the denervated area and soon disappeared spontaneously. Six years later she remained well.

Two additional cases of severe unexplained abdominal pain have recently been contributed by Grimson and his colleagues (1947). Both were young individuals in their thirties with epigastric distress, nausea, and vomiting. These attacks came with increasing frequency and severity. The only abnormality discovered was the fluoroscopic evidence of abnormal peristalsis in the stomach and duodenum. At exploration no evidence of disease could be found. In these Grimson carried out subdiaphragmatic vagotomy in addition to right coeliac and superior mesenteric ganglionectomy. Both patients, as a result of the added vagotomy, developed symptoms of gastric retention. These were fortunately of brief duration, but the authors wisely conclude that this part of the operation is both unnecessary and undesirable. As a result of the sympathetic denervation there was complete relief of pain and both patients were able to return to their normal occupations.

presacral neurectomy, making cervical incisions for biopsy is still painful while the uterine fundus is insensitive. It is of interest that a third of their 24 patients who had subsequent pregnancies felt no cramps with their uterine contractions during the first stage of labour. Several, however, still felt pain in the low back and all experienced pain as the baby passed through the lower birth canal. Patients who are subjected to this operation should be warned that they may have no early labour pains and should call the obstetrician as soon as they first become aware of regular uterine contractions.

A number of papers (Fontaine and Herrmann, 1932; Wetherell, 1933; Greenhill and Schmitz, 1933; Adson and Masson, 1934) have advocated presacral neurectomy for relief of pain in malignant disease of the uterus and cervix. We do not believe that this operation can often be successful and are in agreement with de Sousa Pereira (1946), who recognized the fact that "abdominopelvic sympathectomy relieves only the visceral sympathetic pain, which remains relieved while the tumor is localized within the area anesthetized by the sympathetic operation." As pointed out above, *pain from visceral carcinoma generally does not arise as long as the disease is confined to a viscus. In the case of the uterus there is early direct involvement of the lumbosacral plexus as the malignant cells invade the broad ligaments and para-aortic nodes. The resultant pain radiates to the legs and buttocks, as well as to the lumbar region. Bilateral section of the spinothalamic tracts is a most satisfactory method of obtaining relief at this stage* (see pp. 593-602).

G. RELIEF OF VISCERAL PAIN OF UNKNOWN ORIGIN

Occasionally patients are seen who have recurrent bouts of abdominal pain with all the characteristics of visceral colic, but in whom no etiological factor can be determined either within the abdominal cavity or in the central nervous system. A number of cases of this sort have been described by Archibald (1928), Scrimger (1929), Grimson, Hesser, and Kitchin (1947), and White in his book with Smithwick and Simeone (1952). In problems of this sort, where pain is so severe that the sufferer is driven to depend on narcotics or is developing psychoneurotic symptoms, diagnostic paravertebral block of the splanchnic nerves with procaine is well worth a trial before resort to cordotomy or leucotomy. If successful the block should be repeated on a number of occasions, alternating with injections of inert saline solution. When the latter is without effect and psychiatric examination has excluded a functional origin, splanchnicectomy has given some brilliant results. The surgeon must, however, be constantly on his guard lest he be deceived by the psychoneurotic individual or the deliberate malingerer.

BIBLIOGRAPHY

ABBE, R.: A contribution to the surgery of the spine. *Med. Rec., New York*, 35:149-152, 1889.

ABBE, R.: Resection of posterior roots of spinal nerves to relieve pain, pain reflex, athetosis, and spastic paralysis — Dana's operation. *Med. Rec., New York*, 79:377-381, 1911.

ABRAMS, A.A.: Obliteration of pain at the site of reference by intradermal infiltration anesthesia in first-stage labor. Preliminary report. *New England J. Med.*, 213:636-640, 1930.

ADAMS, R.D. and MUNRO, D.: Surgical division of the spinothalamic tract in the medulla. *Surg., Gynec. & Obst.*, 78:591-599, 1944.

ADRIAN, E.D.: The messages in sensory nerve fibres and their interpretation. *Proc. Roy. Soc., London, s. B*, 109:1-18, 1931.

ADRIAN, E.D.: Afferent discharges to the cerebral cortex from peripheral sense organs. *J. Physiol.*, 100:159-191, 1941.

ADRIAN, E.D., CATTELL, McK. and HOAGLAND, H.: Sensory discharges in single cutaneous nerve fibres. *J. Physiol.*, 72:377-391, 1931.

ADRIANI, J., PARMLEY, J., and OCHSNER, A.: Fatalities and complications after attempts at stellate ganglion block. *Surgery*, 32:615-619, 1952.

ADSON, A.W.: The surgical treatment of glossopharyngeal neuralgia. *Arch. Neurol. & Psychiat.*, 12:487-506, 1924.

ADSON, A.W.: The diagnosis and surgical treatment of trigeminal neuralgia. *Ann. Otol. Rhin. & Laryng.*, 35:601-631, 1926.

ADSON, A.W.: Cervicothoracic ganglionectomy, trunk resection, and ramisectomy by the posterior intrathoracic approach. *Am. J. Surg.*, 11:227-232, 1931.

ADSON, A.W.: Splanchnic pain. *Proc. Staff Meet., Mayo Clin.*, 10:623-624, 1935A.

ADSON, A.W.: Trigeminal neuralgia: Diagnosis and treatment. *Surg. Clin. North America*, 15:1359-1365, 1935B.

ADSON, A.W. and MASSON, J.C.: Dysmenorrhea relieved by resection of presacral sympathetic rami. *J.A.M.A.*, 102:986-990, 1934.

AIRD, R.B. and NAFFZIGER, H.C.: Experimental injection of ethyl alcohol into the lumbar subarachnoid space with neuropathological studies. *West. J. Surg.*, 43:377-387, 1935.

ALEXANDER, J., MACLEOD, A.G. and BARKER, P.S. Sensibility of the exposed human heart and pericardium. *Arch. Surg.*, 19:1470-1483, 1929.

ALEXANDER, L. and KENNEDY, P.C.: Myelomalacia following rhizotomy and its relation to the circulation of the spinal cord. *Tr. Am. Neurol. A.*, 135-137, 1939.

ALEXANDER, W.F.: The innervation of the biliary system. *J. Comp. Neurol.*, 72:357-370, 1940.

ALLBRITTEN, F.F. and MALTBY, G.L.: Causalgia secondary to injury of the major peripheral nerves. Treatment by sympathectomy. *Surgery*, 19:407-414, 1946.

ARCHIBALD, E. Effect of sympathectomy upon the pain of organic disease of arteries of the lower limbs and for obscure abdominal pain. *Ann. Surg.*, 88:499-509, 1928.

ARIENS KAPPERS, C.U., HUBER, G.C., and CROSBY, E.C.: *The Comparative Anatomy of the Nervous System of Vertebrates, Including Man.* New York, Macmillan, 1936, Vol. 1, 864 pp.

Association for Research in Nervous and Mental Disease. Research Publications of. Vol. XXIII. *Pain.* Baltimore, Williams & Wilkins, 1943, 468 pp.

ATLAS, L.N.: Saphenous neurectomy in the treatment of selected cases of painful ulceration of the leg. *Surgery*, 28:37-43, 1950.

AVELLIS, G. Typische Form von Kehlkopfneuralgie. *Munch. med. Wchnschr.*, 47:1592-1594, 1900.

BABTCHINE, I.S. Über die bei der Ausführung der Chordotomie vorkommenden technischen Fehler und Komplikationen. *Beitr. klin. Chir.*, 146:721-731, 1929.

BABTCHINE, I.S. Les résultats immédiats et lointains de la cordotomie. *J. Chir.*, 47:26-39, 1936.

H. POTENTIAL DANGERS OF VISCERAL DESENSITIZATION

In completing this chapter on methods of relieving chronic abdominal pain it is worth considering whether visceral desensitization may subject the patient to subsequent risk from removal of the usual warning symptoms of acute abdominal disease. Weeks, Ryan, and Van Hoy (1946) reported a case of fatal peritonitis as a result of painless perforation of a duodenal ulcer after combined vagotomy and sympathectomy. Such an accident must, however, be an extremely rare occurrence because acid gastric contents, leaking through a perforation, will ordinarily evoke a painful response from the somatic nerve endings in the parietal peritoneum. This is also true with inflammation of the gall bladder and appendix. Craig, Morlock, and Hightower (1950) have investigated the later course of 21 individuals with known peptic ulcers who had had extensive sympathectomies for hypertension performed at the Mayo Clinic. They were led to conclude that "the findings do not substantiate the view that splanchnicectomy and thoracolumbar sympathetic ganglionectomy may increase the risk of complications of an ulcer that exists at the time of these operations." On the whole the course of patients with ulcers has been remarkably little changed. These findings have been corroborated by White, Smithwick, and Simeone (1952), with the exception that Smithwick has observed an increased tendency for the ulcers to bleed. Insofar as we are aware, there have been no reports of other acute abdominal emergencies (appendicitis, cholecystitis, twisted ovarian cysts, etc.) developing silently after extensive splanchnic denervation. The fact that in Dr. Smithwick's large series and the many hundred cases observed in the Massachusetts General Hospital there have been no serious complications is reassuring evidence that there is no appreciable risk on this score.

We conclude these two final chapters of this book with re-emphasis of the importance of a thorough knowledge of the pathology involved in the production of pain, as well as of the fundamental anatomy and physiology concerned with its propagation to the sentient areas in the brain. With these recently acquired facts in mind the surgeon can select the simplest and least radical form of denervation, which in the common varieties of cardiac and upper abdominal pain will result in a very high proportion of successful results with a minimal chance of disagreeable complications.

BETHE, A.: Die Nervenendigungen im Gaumen und in der Zunge des Frosches. *Arch. mikr. Anat.*, *44*:185-200, 1894.

BIGELOW, N., HARRISON, I., GOODELL, H. and WOLFF, H.G.: Studies on pain: Quantitative measurements of two pain sensations of the skin, with reference to the nature of the "hyperalgesia of peripheral neuritis." *J. Clin. Investigation*, *24*:503-512, 1945.

BISCHOFF, E.P.E.: *Mikroskopische Analyse der Anastomosen der Kopfnerven.* Munich, J.J. Lentner, 1865, 52 pp., 13 pl.

BLUMGART, H.L. and FREEDBERG, A.S.: The heart and the thyroid: With particular reference to I[131] treatment of heart disease. *Circulation*, *6*:222-237, 1952.

BLUMGART, H.L., FREEDBERG, A.S. and KURLAND, G.S.: Hypothyroidism produced by radioactive iodine (I[131]) in the treatment of euthyroid patients with angina pectoris and congestive heart failure: Early results in various types of cardiovascular diseases and associated pathologic states. *Circulation*, *1*:1105-1141, 1950.

BLUMGART, H.L., FREEDBERG, A.S. and KURLAND, G.S.: Treatment of incapacitated euthyroid cardiac patients by producing hypothyroidism with radioactive iodine. *New England J. Med.*, *245*:83-91, 1951.

BLUMGART, H.L., LEVINE, S.A. and BERLIN, D.D.: Congestive heart failure and angina pectoris. The therapeutic effect of thyroidectomy on patients without clinical or pathologic evidence of thyroid toxicity. *Arch. Int. Med.*, *51*:866-877, 1933.

BLUMGART, H.L., SCHLESINGER, M.J. and DAVIS, D.: Studies on the relation of the clinical manifestations of angina pectoris, coronary thrombosis, and myocardial infarction to the pathological findings, with particular reference to the significance of the collateral circulation. *Am. Heart J.*, *19*:1-91, 1940.

BOCHENEK, A.: La racine bulbo-spinale du trijumeau et ses connexions avec les trois branches périphériques. *Névraxe*, 3:109-119, 1901.

BOEKE, J.: Innervationsstudien. VIII. Zur Innervation der Cornea bei Saugern. Die Innervierung des Bindegewebes der Cornea bei Macacus rhesus. *Z. mikr.-anat. Forsch.*, *38*:594-618, 1935.

BOENNINGHAUS, G.: Über einen eigenartigen sensorischen Reizungszustand des oberen und unteren Kehlkopfnerven. *Arch. Laryng.*, *18*:197-228, 1906.

BOGLE, J.H.: Calculosis and fibrosis of the pancreas. *Surgery*, *26*:241-250, 1949.

BOK, S.T.: Das Ruckenmark, in *Handbuch der mikroskopischen Anatomie des Menschen*, edited by MOLLENDORFF, Berlin, Springer, 1929, Vol. IV.

BOLDREY, E.: Amputation neuroma in nerves implanted in bone. *Ann. Surg.*, *118*:1052-1058, 1943.

BONNER, F., COBB, S., SWEET, W.H. and WHITE, J.C.: Frontal lobe surgery in the treatment of pain with consideration of postoperative psychological changes. *Psychosom. Med.*, *14*:383-405, 1952.

BORING, E.G.: Cutaneous sensation after nerve-division. *Quart. J. Exper. Physiol.*, *10*:1-95, 1916.

BORNSTEIN, B.: Sur le phénomène du membre fantôme. *Encéphale*, *38*:32-46, 1949.

BORS, E. and FRENCH, J.D.: Management of paroxysmal hypertension following injuries to cervical and upper thoracic segments of the spinal cord. *Arch. Surg.*, *64*:803-812, 1952.

BOTTERELL, E.H., JOUSSE, A.T., ABERHART, C. and CLUFF, J.W.: Paraplegia following war. *Cincinnati J. Med.*, *27*:595-623, 1946.

BOYD, D.A., JR. and NIE, L.W.: Congenital universal indifference to pain. *Arch. Neurol. & Psychiat.*, *61*:402-412, 1949.

BRADFORD, F.K. and SPURLING, R.G.: *The Intervertebral Disc.* Springfield, Illinois, Thomas, 1945, 192 pp.

BRAEUCKER, W.: Der Brustteil des vegetativen Nervensystems und seine klinisch-chirurgische Bedeutung. *Beitr. Klin. Tuberk.*, *66*:1-65, 1927.

BRAEUCKER, W.: Die Anatomie und Chirurgie des vegetativen Nervensystems. *Deutsche Ztschr. Nervenh.*, *106*:137-195, 1928.

BRASHEAR, A.D.: Innervation of the teeth. *J. Am. Dent. A.*, 23:662-668, 1936.

BABTSCHIN (German spelling) — *see* BABTCHINE (French spelling).
BAGDASAR, M.D.: La chordotomie. Considérations sur la voie de conduction de la douleur. *Rev neurol.*, *68* 353-358, 1937.
BAILEY, A.A. and MOERSCH, F.P.: Phantom limb. *Canad.M A J.*, *45*:37-42, 1941.
BAILEY, P.: Glossopharyngeal neuralgia. *Surg. Clin. North America*, *11*:72-74, 1931.
BAILEY, P. and BREMER, F.: A sensory cortical representation of the vagus nerve. With a note on the effects of low blood pressure on the cortical electrogram. *J. Neurophysiol.*, *1*.405-412, 1938
BAILEY, P., DUSSER DE BARENNE, J.G., GAROL, H.W. and MCCULLOCH, W.S.: Sensory cortex of chimpanzee *J. Neurophysiol*, *3*.469-485, 1940.
BAILEY, P. and SWEET, W.H.: Effects on respiration, blood pressure and gastric motility of stimulation of orbital surface of frontal lobe. *J. Neurophysiol.*, *3*.276-281, 1940.
BALCHUM, O.J and WEAVER, H M : Pathways for pain from the stomach of the dog. *Arch. Neurol & Psychiat.*, *49* 739-753, 1943
BANZET, P.M . *La cordotomie Étude anatomique, technique, clinique, et physiologique.* (Thèse pour le doctorat en médecine, Nancy.) Paris, Libraire Louis Arnette, 1927, 118 pp
BARCLAY, J.H : A case of trigeminal neuralgia in a boy age 10 years, treated by intracranial division of the second and third divisions of the nerve. *Brit J. Surg.*, *9*.306-308, 1922.
BAUDOUIN, A and PUECH, P.: Sur quelques essais de thalamotomie. *IVe Congr. Neurol. int.*, *2*.44-45, 1949
BAUER, G . Treatment of hydronephrosis and renal pain by denervation of the kidney. *Acta chir. scandinav.*, *83*·160-184, 1939.
BAUER, G . Late results of denervation of the kidney for renal pain. *Acta chir. scandinav.*, *90*.460-468, 1944
BAUER, K H.: Die Elektrokoagulation des Ganglion Gasseri. *Chirurg*, *16*:1-5, 1944.
BAYLES, T.B , JUDSON, W E. and POTTER, T.A.: Reflex sympathetic dystrophy of the upper extremity (hand-shoulder syndrome). *J.A M A.*, *144* 537-542, 1950.
BAYLISS, W M.: On the origin from the spinal cord of the vaso-dilator fibres of the hind-limb, and on the nature of these fibres *J. Physiol*, *26*:173-209, 1901.
BAZETT, H C. and MCGLONE, B : Note on the pain sensations which accompany deep punctures *Brain*, *51*.18-23, 1928.
BAZETT, H C., MCGLONE, B., WILLIAMS, R.G. and LUFKIN, H.M.: Depth distribution and probable identification in the prepuce of sensory end-organs concerned in sensations of temperature and touch, thermometric conductivity *Arch Neurol. & Psychiat*, *27*:489-517, 1932.
BECK, C.S The relief of intractable pain by section of the anterolateral columns of the spinal cord (cordotomy) Report of three cases *Ohio State M. J.*, *25*:455-460, 1929.
BECK, C S.: Revascularization of the heart. *Ann. Surg*, *128*·854-864, 1948.
BEECHER, H K Pain in men wounded in battle *Ann Surg.*, *123* 96-105, 1946.
BEECHER, H.K Acidosis during thoracic surgery. *J Thoracic Surg*, *19* 50-70, 1950.
BEER, E.: The relief of intractable and persistent pain due to metastases pressing on nerve plexuses *J.A.M A*, *60*.267-269, 1913.
BENNET, W.H.: A case in which acute spasmodic pain in the left lower extremity was completely relieved by subdural division of the posterior roots of certain spinal nerves. *Med.-chir. Trans*, *72*.329-348, 1889
BENTLEY, F H : The interpretation of visceral pain. *Ann Roy Coll Surg. England*, Dec., 328-335, 1948A.
BENTLEY, F H.: Observations on visceral pain. (1) Visceral tenderness. *Ann Surg*, *128* 881-887, 1948B.
BENTLEY, F.H. and SMITHWICK, R.H.: Visceral pain produced by balloon distension of the jejunum. *Lancet*, *239* 389-391, 1940
BERNARD, C : *Leçons sur les propriétés des tissus vivants* Paris, J. B Baillière et fils, 1866, 243 pp
BERNHARDT, M.: Ueber isolirt im Gebiete des N cutaneus femoris externus vorkommende Parasthesien. *Neurol. Centralbl., Leipzig*, *14* 242-244, 1895.

CHANDLER, F.A. and SLIDER, F.: Intrapelvic extraperitoneal resection of the obturator nerve. *Surg. Gynec. & Obst.*, 69:100-102, 1939.

CHAPMAN, W.P., LIVINGSTON, R.B., LIVINGSTON, K.E. and SWEET, W.H.: Possible cortical areas involved in arterial hypertension. *Research Publ. A. Nerv. & Ment. Dis.*, 29:775-798, 1950.

CHOROBSKI, J. and PENFIELD, W.: Cerebral vasodilator nerves and their pathway from the medulla oblongata. *Arch. Neurol. & Psychiat.*, 28:1257-1289, 1932.

CLARK, L.P. and TAYLOR, A.S.: True tic douloureux of the sensory filaments of the facial nerve. *J.A.M.A.*, 53:2144-2146, 1909.

CLARK, W.E.Le G.: The termination of ascending tracts in the thalamus of the Macaque monkey, *J. Anat., Lond.*, 71:7-40, 1936.

CLARK, W.E.Le G.: *Anatomical Pattern as the Essential Basis of Sensory Discrimination.* (Forty-ninth Robert Boyle Lecture, Oxford University, May 29, 1947.) Oxford, Blackwell Scientific Publications, 1947, 16 pp.

CLELAND, J.G.P.: Paravertebral anesthesia in obstetrics: Experimental and clinical basis. *Surg., Gynec. & Obst.*, 57:51-62, 1933.

CLEVELAND, D.A.: Afferent fibers in the cervical sympathetic trunk, superior cervical ganglion, and internal carotid nerve. *J. Comp. Neurol.*, 54:35-43, 1932.

COBB, S.: Cutaneous sensibility in cases of peripheral nerve injury: Epicritic and protopathic hypothesis of Head untenable. *Arch. Neurol. & Psychiat.*, 2:505-517, 1919.

COBB, S.: *Borderlands of Psychiatry.* Cambridge, Harvard University Press, 1943, 166 pp.

COBB, S.: Amnesia for the left limbs developing into anosognosia. *Bull. Los Angeles Neurol. Soc.*, 12:48-52, 1947.

COBB, S.: *Emotion and Clinical Medicine.* New York, Norton, 1950, 243 pp.

COBB, S.: *Foundations of Neuropsychiatry.* Baltimore, Williams & Wilkins, 5th ed., 1952, 287 pp.

COBB, S. and FINESINGER, J.E.: Cerebral circulation. The vagal pathway of the vasodilator impulses. *Arch. Neurol. & Psychiat.*, 28:1243-1256, 1932.

COBURN, D.F.: Painful stumps and their treatment. *U.S. Nav. Med. Bull.*, 44:1194-1196, 1945.

COFFEY, W.B. and BROWN, P.K.: The surgical treatment of angina pectoris. *Arch. Int. Med.*, 31:200-220, 1923.

COHEN, H.: The mechanism of visceral pain. *Tr. Med. Soc. London*, 64:35, 1944.

CONNOLLY, J.E. and RICHARDS, V.: Bilateral splanchnicectomy and lumbodorsal sympathectomy for chronic relapsing pancreatitis. *Ann. Surg.*, 131:58-63, 1950.

COOK, A.W. and DRUCKEMILLER, W.H.: Phantom limb in paraplegic patients. Report of two cases and an analysis of its mechanism. *J. Neurosurg.*, 9:508-516, 1952.

CORLETTE, C.E.: Meralgia paraesthetica (tension neuritis of the lateral femoral cutaneous nerve). *Med. J. Australia*, 31[1]:127-129, 1944.

COSTEN, J.B.: A syndrome of ear and sinus symptoms dependent upon disturbed function of the temporomandibular joint. *Ann. Otol. Rhin. Laryng.*, 43:1-15, 1934.

COSTEN, J.B.: Neuralgias and ear symptoms associated with disturbed function of the temporomandibular joint. *J.A.M.A.*, 107:252-255, 1936.

COTTE, G.: Sur le traitement des dysménorrhées rebelles par la sympathectomie hypogastrique périartérielle ou la section du nerf présacré. *Lyon méd.*, 135:153-159, 1925.

CRAIG, W.McK.: The hemicrania of migraine. *Proc. Staff Meet., Mayo Clin.*, 10:362-364, 1935.

CRAIG, W.McK.: The diagnosis and treatment of trigeminal neuralgia. *South. Surgeon*, 10:17-29, 1941.

CRAIG, W.McK., MORLOCK, C.G. and HIGHTOWER, N.C., JR.: The influence of sympathectomy on the gastrointestinal tract. *Surg. Clin. North America*, 30:1035-1043, 1950.

CRAWFORD, A.S.: Medullary tractotomy for relief of intractable pain in upper levels. *Arch. Surg.*, 55:523-529, 1947.

BRAZIER, M.A.B: *The Electrical Activity of the Nervous System.* New York, Macmillan, 1951, 220 pp.

BREGMAN, E: Ueber experimentelle aufsteigende Degeneration motorischer und sensibler Hirnnerven. *Arb neurol. Inst. Univ. Wien, 1*:73-97, 1892.

BRICKNER, R.M. and RILEY, H.A.: Autonomic facio-cephalalgia. *Bull. Neurol. Inst., New York, 4* 422-431, 1935.

BRODAL, A.: Central course of afferent fibers for pain in facial glossopharyngeal and vagus nerves: Clinical observations. *Arch. Neurol. & Psychiat*, *57*.292-306, 1947*A*.

BRODAL, A.. The hippocampus and the sense of smell. *Brain, 70*:179-222, 1947*B*.

BROWDER, E J. Discussion of paper by C. G. de GUTIÉRREZ-MAHONEY: Treatment of painful phantom limb by removal of the postcentral cerebral cortex. *Arch. Neurol. & Psychiat*, *64*.894-896, 1950.

BROWDER, [E.] J. and de VEER, J.A.: Herpes zoster. A surgical procedure for the treatment of postherpetic neuralgia. *Ann. Surg*, *130*.622-636, 1949.

BROWDER, [E.] J and GALLAGHER, J.P.: Surgical treatment of painful phantom limb. *New York State J Med*, *46*.2403-2405, 1946.

BROWDER, E J and GALLAGHER, J P.: Dorsal cordotomy for painful phantom limb. *Ann. Surg*, *128* 456-469, 1948

BUCY, P C.: Discussion of paper by W.H. SWEET, J.C. WHITE, B. SELVERSTONE and R. NILGES: Sensory responses from anterior roots and from surface and interior of spinal cord in man. *Tr. Am Neurol. A*, 165-169 (p. 168), 1950.

BUES, E.: Tractotomie bei Glossopharyngeus- und Facialis-Neuralgie. *Acta Neurochir*, *3*:38-50, 1952

BUNNELL, S. *Surgery of the Hand* Philadelphia, Lippincott, 1944, 734 pp.

BYCHOWSKY, G and EIDINOW, M · Doppelseitige Sensibilitatsstorungen bei einseitigen Gehirnherden. *Nervenarzt, 7*:498-506, 1934

CADWALDER, W B. and SWEET, J.E.: Experimental work on the function of the anterolateral column of the spinal cord. *J.A.M A*, *58*.1490-1493, 1912.

[RAMON Y] CAJAL, S.: Nueva contribucion al estudio del bulbo raquideo. V. Sobre un fasciculo especial del vago-glosofaringeo que se asocia al quinto par. *Rev. trim. microg., Madrid, 2* 67-99, 1897.

[RAMON Y] CAJAL, S: *Histologie du système nerveux* Paris, Maloine, 1909, 2 vols.

[RAMON Y] CAJAL, S.: *Degeneration and regeneration of the nervous system.* London, Oxford University Press, 1928, 2 vols.

CALDWELL, G A., BRODERICK, T F., JR. and ROSE, R.M.: Sympathetic block of the stellate ganglion. Its application in orthopaedic conditions. *J. Bone & Joint Surg*, *28*·513-520, 1946

CAMITZ, H.: Die deformierende Huftgelenksarthritis und speziell ihre Behandlung *Acta orthop. scandinav.*, *4*.193-213, 1933.

CAMPBELL, E. and WHITFIELD, R D: Surgical treatment of intractable pain *Surg. Clin North America, 30* 349-362, 1950

CANNON, B: A method of stimulating autonomic nerves in the unanaesthetized cat with observations on the motor and sensory effects *Am. J. Physiol.*, *105*.366-372, 1933

CANNON, W.B.: *The Wisdom of the Body.* New York, Norton, 1932, 312 pp.

CARPENTER, M.B. and WHITTIER, J.R.: Study of methods for producing experimental lesions of the central nervous system with special reference to stereotaxic technique. *J. Comp. Neurol*, *97*:73-131, 1952.

CASSA and GRINDA: Traitement de la névralgie du trijumeau par coagulation du ganglion de Gasser suivant la technique de Kirschner. *Rev. neurol., 78*.163-164, 1946.

de CASTRO, F.: Sensory ganglia of the cranial and spinal nerves, normal and pathological. Section III of Vol. I, *Cytology and Cellular Pathology of the Nervous System*, edited by W. PENFIELD, New York, Hoeber, 1932, pp. 93-143.

ČERNÝ, R.: Autodermography. A new and simple method of demonstrating the propagation of pain and disorders of surface sensibility. *J. Neurosurg., 4*:188-190, 1947.

DENNY-BROWN, D., ADAMS, R.D. and FITZGERALD, P.J.: *Pathologic features of herpes zoster. A note on "geniculate herpes."* *Arch. Neurol. & Psychiat.*, *51*:216-231, 1944.

D'ERRICO, A.: *Intramedullary spinothalamic tractotomy. J. Neurosurg.*, *7*:294-298, 1950.

DESAUSSURE, R.L., JR.: Lateral spinothalamic tractotomy for the relief of pain in cauda equina injury. *Arch. Neurol. & Psychiat.*, *64*:708-714, 1950.

DICKINSON, D.G.: Surgical relief of the headache of migraine. *J. Nerv. & Ment. Dis.*, *77*:42-52, 1933.

DICKMANN, G.H. and BULLAS, D.T.: Lobotomia prefrontal unilateral, en la anestesia dolorosa y en las algias faciales atipicas. *Prensa méd. argent.*, 36:1483-1485, 1949.

DOGIEL, A.S.: Die Nerven der Cornea des Menschen. *Anat. Anz.*, 5:483-494, 1890.

DOGIEL, A.S.: Der Bau der Spinalganglien bei den Saugetieren. *Anat. Anz.*, *12*:140-152, 1896.

DOGIEL, A.S.: *Die sensiblen Nervenendigungen im Herzen und in den Blutgefassen der Saugethiere.* *Arch. mikr. Anat.*, 52:44-70, 1898.

DOGIEL, A.S.: Die Nervenendigungen im Bauchfell in den Sehen des Muskelspindeln und dem Centrum tendineum des Diaphragmas beim Menschen und bei Saugethieren. *Arch. mikr. Anat.*, *59*:1-31, 1902.

DOGLIOTTI, A.M.: Traitement des syndromes douloureux de la périphérie par l'alcoolisation sub-arachnoïdienne des racines postérieures à leur émergence de la moelle épinière. *Presse méd.*, 39:1249-1252, 1931.

DOGLIOTTI, A.M.: First surgical sections, in man, of the lemniscus lateralis (pain-temperature path) at the brain stem, *for the treatment of diffused rebellious pain. Anesth. & Analg.*, *17*:143-145, 1938.

DOUPE, J., CULLEN, C.H. and CHANCE, G.Q., Post-traumatic pain and the causalgic syndrome. *J. Neurol. Neurosurg. & Psychiat.*, 7:33-48, 1944.

DOWNMAN, C.B. and AMASSIAN, V.E.: Cited by J. F FULTON in paper on "Recent advances in neurophysiology" presented at meeting of Harvey Cushing Society, Hollywood, Florida, Apr. 23, 1953.

DOYLE, J.B.: A study of four cases of glossopharyngeal neuralgia. *Arch. Neurol. & Psychiat.*, 9.34-46, 1923.

DRAGSTEDT, L.R. and PALMER, W.L.: *Direct observation on the mechanism of pain in duodenal ulcer. Proc. Soc. Exper. Biol. Med.*, 29:753-755, 1932.

DURANT, T.M., LONG, J. and OPPENHEIMER, M.J.: Pulmonary (venous) air embolism. *Am. Heart J.*, 33:269-281, 1947.

DUSSER DE BARENNE, J.G : Physiologie der Grosshirnrinde, in *Handbuch der Neurologie*, edited by BUMKE and FOERSTER, Berlin, Springer, 1937, Vol. 2, pp. 268-319.

EBIN, J.: Combined lateral and ventral pyramidotomy in treatment of paralysis agitans. *Arch. Neurol. & Psychiat.*, 62:27-47, 1949.

ECHLIN, F.: *Pain responses on stimulation of the lumbar sympathetic chain under local anesthesia. A case report. J. Neurosurg.*, 6:530-533, 1949.

ECHLIN, F, OWENS, F.M., JR. and WELLS, W.L.: Observations on "*major*" and "*minor*" causalgia. *Arch. Neurol. & Psychiat*, 62.183-203, 1949.

ECHOLS, D.H and COLCLOUGH, J A : Abolition of painful phantom foot by resection of the sensory cortex. *J.A M A*, *134*.1476-1477, 1947.

ECHOLS, D.H. and MAXWELL, J.H.. Superior laryngeal neuralgia relieved by operation. *J.A.M.A.*, *103*.2027-2028, *1934*.

ECKER, A D. and WOLTMAN, H.W · *Meralgia paraesthetica:* A report of one hundred and fifty cases *J.A.M A*, *110* 1650-1652, 1938.

von ECONOMO, C Über dissozuerte Empfindungslahmung bei Ponstu*moren und* uber die zentralen Bahnen des sensiblen Trigeminus. *Jahrbuch Psychiat. & Neurol.*, *32*:107-138, 1911.

EDDS, M.V ,JR Prevention of nerve regeneration and neuroma formation by caps of synthetic resin. *J Neurosurg*, *2* 507-509, *1945*.

EDINGER, L : *Vergleichend-entwicklungsgeschichtliche* und anatomische Studien im Bereiche des Centralnervensystems: II. Über *die Fortsetzung der hinteren* Ruckenmarkswurzeln zum Gehirn *Anat Anz.*, *4*:121-128, 1889.

CRONHOLM, B.: Phantom limbs in amputees: A study of changes in the integration of centripetal impulses with special reference to referred sensations. *Acta psychiat. neurol. scandinav.*, Suppl. 72. Stockholm, Haeggstrom, 1951, 310 pp.

CUSHING, H.: A method of total extirpation of the Gasserian ganglion for trigeminal neuralgia. *J.A.M.A.*, *34*:1035-1041, 1900.

CUSHING, H: The rôle of deep alcohol injections in the treatment of trigeminal neuralgia. *J.A.M.A*, *75*.441-443, 1920A.

CUSHING, H.: The major trigeminal neuralgias and their surgical treatment based on experiences with 332 Gasserian operations. *Am. J. M. Sc.*, *160*:157-184, 1920B.

DANDY, W.E.: Glossopharyngeal neuralgia (tic douloureux): Its diagnosis and treatment. *Arch Surg*, *15*.198-214, 1927.

DANDY, W.E.: An operation for the cure of tic douloureux. Partial section of the sensory root at the pons *Arch. Surg*, *18*.687-734, 1929A.

DANDY, W.E. Operative relief from pain in lesions of the mouth, tongue and throat. *Arch. Surg.*, *19*.143-148, 1929B.

DANDY, W E.. Treatment of hemicrania (migraine) by removal of inferior cervical and first thoracic sympathetic ganglion. *Bull. Johns Hopkins Hosp*, *48*.357-361, 1931.

DANDY, W.E.: The treatment of trigeminal neuralgia by the cerebellar route. *Ann. Surg*, *96*.787-795, 1932.

DANDY, W E.: Physiological studies following extirpation of the right cerebral hemisphere in man. *Bull. Johns Hopkins Hosp*, *53*:31-51, 1933.

DANDY, W.E.. Concerning the cause of trigeminal neuralgia. *Am. J. Surg*, *24*.447-455, 1934.

DANDY, W.E.. Surgery of the brain, in *Practice of Surgery*, edited by D. LEWIS, Hagerstown, Md, Prior, 1945, Vol. 12

DANIÉLOPOLU, D.: État actuel du traitement chirurgical de l'angine de poitrine *Cardiologia*, *14*.1-80, 1949.

DARWIN, E . *Zoonomia. or, the Laws of Organic Life.* London, J. Johnson, 1794, vol 1.

DAVID, M , TALAIRACH, J. and HÉCAEN, H.: Étude critique des interventions neuro-chirurgicales actuellement pratiquées dans le traitement de la douleur. *Semaine Hôp. Paris*, *23*.1651-1665, 1947.

DAVIS, L.: The surgical treatment of intractable pain. *J.A.M.A.*, *101*.1921-1925, 1933.

DAVIS, L , HART, J.T. and CRAIN, R.C . The pathway for visceral afferent impulses within the spinal cord. II. Experimental dilatation of the biliary ducts. *Surg. Gynec. & Obst*, *48* 647-651, 1929.

DAVIS, L. and HAVEN, H.A.: Surgical anatomy of the sensory root of the trigeminal nerve. *Arch. Neurol & Psychiat.*, *29* 1-15, 1933.

DAVIS, L and MARTIN, J.: Studies upon spinal cord injuries. II. The nature and treatment of pain *J. Neurosurg.*, *4*.483-491, 1947.

DAVIS, L , MARTIN, J and GOLDSTEIN, S.L.: Sensory changes with herniated nucleus pulposus. *J Neurosurg.*, *9*.133-138, 1952.

DAVIS, L. and POLLOCK, L J.: The peripheral pathway for painful sensations. *Arch Neurol. & Psychiat.*, *24*.883-898, 1930.

DAVIS, L and POLLOCK, L.J.: The rôle of the sympathetic nervous system in the production of pain in the head. *Arch. Neurol. & Psychiat.*, *27*.282-293, 1932.

DAVIS, L , POLLOCK, L J. and STONE, T.T : Visceral pain. *Surg , Gynec. & Obst*, *55*:418-427, 1932.

DAVISON, C. and SCHICK, W.: Spontaneous pain and other subjective sensory disturbances *Arch. Neurol. & Psychiat.*, *34*.1204-1237, 1935

DÉJERINE, J. and ROUSSY, G.: Le syndrome thalamique *Rev neurol*, *14*.521-532, 1906.

DELGADO, J.M.R. and LIVINGSTON, R B : Some respiratory, vascular and thermal responses to stimulation of orbital surface of frontal lobe. *J. Neurophysiol*, *11*:39-55, 1948.

DELL, P. and OLSON, R : Projections thalamiques, corticales et cérébelleuses des afférences viscérales vagales. *Compt. rend. Soc. Biol., Paris*, *145*.1084-1088, 1951.

Finlayson, A.L.: Cervicogenic cephalalgia: Unilateral head pain related to upper cervical spinal nerve roots. Presented at the meeting of the Society of Neurological Surgeons, Omaha, Neb., June 11, 1948.

Flothow, P.G.: Relief of pain from the neurologic viewpoint. *Northwest Med.*, 29 69-76, 1930.

von Foerster, H.: (editor) *Cybernetics*. New York, Josiah Macy, Jr., Foundation, 1951, 249 pp.

Foerster, O.: *Die Leitungsbahnen des Schmerzgefühls und die chirurgische Behandlung der Schmerzzustände*, Berlin and Vienna, Urban and Schwarzenberg, 1927A, 360 pp.

Foerster, O.: Ueber die Vorderseitenstrangdurchschneidung. *Arch. Psychiat. Nervenkr.*, *81*:707-717, 1927B.

Foerster, O.: Spezielle Anatomie und Physiologie der peripheren Nerven, in *Handbuch der Neurologie*, edited by Bumke and Foerster, Berlin, Springer, 1929, *Ergänzungsband*, 2.785-974.

Foerster, O.: The dermatomes in man *Brain*, *56* 1-39, 1933.

Foerster, O.: Sensible corticale Felder, in *Handbuch der Neurologie*, edited by Bumke and Foerster, Berlin, Springer, 1936, *6*.358-448

Foerster, O., Altenburger, H. and Kroll, F.W.: Über die Beziehungen des vegetativen Nervensystems zur Sensibilität. *Z ges Neurol Psychiat.*, *121*:139-185, 1929.

Foerster, O. and Gagel, O: Die Vorderseitenstrangdurchschneidung beim Menschen. *Z. ges. Neurol. Psychiat*, *138*.1-92, 1932.

Foerster, O. and Gagel, O. Über afferente Nervenfasern in den vorderen Wurzeln. *Z. ges. Neurol. Psychiat*, *144*.313-324, 1933

Foix, C., Thévenard, A. and Nicolesco, I: Algie faciale d'origine bulbotrigéminale au cours de la syringomyélie. Troubles sympathiques concomitants Douleur à type cellulaire. *Rev. neurol.* 38.990-998, 1922.

Fontaine, R.: Les infiltrations autour de l'artère temporale dans le traitement de la migraine. *Presse méd.*, 39.580, 1943

Fontaine, R. and Herrmann, L G. Clinical and experimental basis for surgery of the pelvic sympathetic nerves in gynecology. *Surg, Gynec. & Obst.*, *54*:133-163, 1932.

Fontaine, R. and Herrmann, L.G.. Post-traumatic painful osteoporosis. *Ann. Surg*, *97*.26-61, 1933.

Ford, F.R. and Wilkins, L. Congenital universal insensitiveness to pain. A clinical report of three cases in children with discussion of the literature *Bull. Johns Hopkins Hosp.*, 62 448-466, 1938

Fowler, G.R.: The operative treatment of facial neuralgia: A comparison of methods and results. *Ann. Surg.*, *3* 269-320, 1886.

François-Franck, C.A.: Signification physiologique de la résection du sympathique dans la maladie de Basedow, l'épilepsie, l'idiotie et le glaucome. *Bull. Acad. Méd. Paris*, *41*:565-594, 1899.

Frazier, C H. A surgeon's impression of trigeminal neuralgia based on experience with 302 cases *J.A.M.A.*, *70* 1345-1350, 1918

Frazier, C.H.: Section of the anterolateral columns of the spinal cord for the relief of pain. A report of six cases. *Arch Neurol & Psychiat*, *4* 137-147, 1920.

Frazier, C H. Pain phenomena of the face, their origin and treatment, with special reference to trigeminal neuralgia *Am. J. M Sc*, *169*·469-476, 1925A

Frazier, C H: Subtotal resection of sensory root for relief of major trigeminal neuralgia *Arch. Neurol. & Psychiat*, *13*:378-384, 1925B

Frazier, C. H: Operation for the radical cure of trigeminal neuralgia. Analysis of five hundred cases. *Ann. Surg.*, *88*:534-547, 1928A.

Frazier, C.H.: Atypical neuralgia: Unsuccessful attempts to relieve patients by operations on the cervical sympathetic system. *Arch Neurol & Psychiat*, *19*.650-659, 1928B.

Frazier, C H: Bilateral trigeminal neuralgia *Ann. Surg.*, *100*·770-778, 1934.

Frazier, C.H., Lewy, F H. and Rowe, S N · The origin and mechanism of paroxysmal neurologic pain and the surgical treatment of central pain. *Brain*, *60*.44-51, 1937.

EDWARDS, W.B. and HINGSON, R.A : Continuous caudal anesthesia in obstetrics. *Am. J. Surg*, *N.S.57*.459-464, 1942.

EFRON, R.: Neurology and the space-time continuum. Presented at the meeting of the Boylston Medical Society of Harvard Medical School, Dec. 12, 1951.

ELAUT, L.: The surgical anatomy of the so called presacral nerve. *Surg., Gynec. & Obst*, 55.581-589, 1932.

ELIASON, E.L. and WELTY, R.F.· Pancreatic calculi. *Ann. Surg., 127*:150-157, 1948.

ELLONEN, A : L'effet de la sympathectomie sur le fantôme douloureux d'un amputé. *Acta chir. scandinav., 93*.131-145, 1946.

ELSBERG, C.A . *Surgical Diseases of the Spinal Cord, Membranes, and Nerve Roots.* New York, Hoeber, 1941, 598 pp.

ENGEL, G L.. Primary atypical facial neuralgia. An hysterical conversion symptom. *Psychosom. Med*, *13*.375-396, 1951.

ERICKSON, T C : Paroxysmal neuralgia of the tympanic branch of the glossopharyngeal nerve. *Arch. Neurol. & Psychiat*, *35*·1070-1075, 1936.

ERICKSON, T.C., BLECKWENN, W.J. and WOOLSEY, C.N.: Observations on the post central gyrus in relation to pain. *Tr. Am. Neurol. A.*, 57-59, 1952.

ERSKINE, C.A. and ROWBOTHAM, G F.: Late changes in the brain stem following trigeminal tractotomy *Arch. Neurol. & Psychiat., 62* 493-502, 1949.

EVANS, J.A.: Sympathectomy for reflex sympathetic dystrophy: Report of twenty-nine cases *J.A.M.A., 132* 620-623, 1946.

EVANS, J.A., POPPEN, J.L. and TOBIAS, J.B.. Relief of angina pectoris by sympathectomy. Report of results in ten patients subjected to high thoracolumbar sympathectomy including the anginal pathway. *J A M.A*, *144*.1432-1436, 1950

EVANS, J.P.: A study of the sensory defects resulting from excision of cerebral substance in humans. *Res. Publ. A. Nerv. Ment Dis., 15* 331-370, 1935.

EWALT, J.R , RANDALL, G C. and MORRIS, H · The phantom limb. *Psychosom. Med*, *9*.118-123, 1947.

EXNER, A : Ein neues Operationsverfahren bei tabischen Crises gastriques. *Deutsches A chir., 111*:576-590, 1911.

FALCONER, M A . Relief of intractable pain of organic origin by frontal lobotomy. *Research Publ. A. Nerv. Ment. Dis., 27*·707-714, 1948

FALCONER, M.A Intramedullary trigeminal tractotomy and its place in the treatment of facial pain. *J Neurol*, *Neurosurg. & Psychiat., 12* 297-311, 1949.

FALCONER, M.A . GLASGOW, G L and COLE, D S.: Sensory disturbances occurring in sciatica due to intervertebral disc protrusions. Some observations on the fifth lumbar and first sacral dermatomes. *J. Neurol*, *Neurosurg & Psychiat*, *10*.72-84, 1947.

FALCONER, M.A. and LINDSAY, J S B Painful phantom limb treated by high cervical chordotomy. Report of two cases. *Brit J. Surg*, *33*:301-306, 1946.

FAUTEUX, M.: Surgical treatment of angina pectoris. Experiences with ligation of the great cardiac vein and pericoronary neurectomy. *Ann Surg., 124*.1041-1046, 1946.

FAY, T Intracranial division of glossopharyngeal nerve combined with cervical rhizotomy for pain in inoperable carcinoma of the throat. *Ann Surg., 84*.456-459, 1926.

FAY, T.: Observations and results from intracranial section of the glossopharyngeus and vagus nerves in man. *J. Neurol Psychopath*, *8*·110-123, 1927.

FAY, T.: Atypical facial neuralgia, a syndrome of vascular pain *Ann Otol. Rhin. & Laryng*, *41*:1030-1062, 1932.

FEIL, H.: Clinical appraisal of the Beck operation *Ann Surg*, *118*.807-815, 1943.

FEINDEL, W.H., WEDDELL, G. and SINCLAIR, D C.. Pain sensibility in deep somatic structures *J. Neurol*, *Neurosurg. & Psychiat., 11*·113-117, 1948

FENTON, R.A. and LARSELL, O.: The mechanism of pain transmission in certain types of otalgia *Ann. Otol. Rhin. & Laryngol., 37*:739-761, 1928

Gardner, W.J., Stowell, A. and Dutlinger, R.: Resection of the greater superficial petrosal nerve in the treatment of unilateral headache. *J. Neurosurg.*, *4*:105-114, 1947.

Gask, G.E.: The surgery of the sympathetic nervous system. (The Bradshaw Lecture, delivered before the Royal College of Surgeons of England, December, 1932.) *Brit. J. Surg.*, *21*:113-130, 1933.

Gaskell, W.H.: *The Involuntary Nervous System.* London, Longmans, Green & Co., 1916, 178 pp.

Gasser, H.S.: Pain-producing impulses in peripheral nerves. *Research Publ. A. Nerv. Ment. Dis.*, 23:44-62, 1943.

Gasser, H.S.: Mammalian nerve fibers, Nobel Lecture given Dec. 12, 1945, included in *Les Prix Nobel en 1940-1944*, Stockholm, P. A. Norstedt, 1946, pp. 128-141.

Gasser, H S. and Erlanger, J.: The rôle of fiber size in the establishment of a nerve block by pressure or cocaine. *Am. J. Physiol.*, 88:581-591, 1929.

Gaudet, L.S.: Spheno-palatine ganglion neuralgia. *New Orleans M. & S. J.*, *77*:114-120, 1924.

von Gaza, W.: Die Resektion der paravertebralen Nerven und die isolierte Durchschneidung des Ramus communicans. *Arch. klin. Chir.*, *133*:479-500, 1924.

van Gehuchten, A.: *Anatomie du système nerveux de l'homme.* Louvain, A. Uystpruyst-Dieudonné, 1900, 2 vols (vol 2).

van Gehuchten, A.: Recherches sur les voies sensitives centrales. La voie centrale du trijumeau. *Névraxe*, *3*:237-261, 1901.

Gerard, M.W.: Afferent impulses of the trigeminal nerve. The intramedullary course of the painful, thermal and tactile impulses. *Arch. Neurol. & Psychiat.*, 9:306-338, 1923.

German, W.: Discussion of paper presented by W. S. Keith on "Glossopharyngeal neuralgia: Recurrence after intracranial section of nerve," at meeting of Harvey Cushing Society, Memphis, Tenn., April, 1938. See abstract in *Zentralbl. Neurochir.*, 3:354, 1938.

Gerstmann, J.: Problem of imperception of disease and of impaired body territories with organic lesions: Relation to body scheme and its disorders. *Arch. Neurol. & Psychiat.*, 48:890-913, 1942.

Gibbon, J.H.,Jr., Albritton, F F,Jr., Stayman, J.W.,Jr. and Judd, J M.: A clinical study of respiratory exchange during prolonged operations with an open thorax. *Ann. Surg.*, *132*: 611-625, 1950.

Glaser, M.A.: Atypical neuralgia, so-called: A critical analysis of 143 cases. *Arch. Neurol. & Psychiat.*, 20:537-558, 1928

Glaser, M.A.: Atypical facial neuralgia. Diagnosis, cause and treatment. *Arch. Int. Med.*, 65:340-367, 1940.

Glees, P. and Bailey, R.A.: Schichtung und Fasergrosse des Tractus spinothalamicus des Menschen. *Mschr Psychiat Neurol.*, *122*:129-141, 1951

Goldscheider, A. Neue Thatsachen uber die Hautsinnesnerven. *Pflüg. Arch. ges. Physiol., Suppl*, *1*:1-110, 1885.

Goldscheider, A.: *Das Schmerzproblem* Berlin, J. Springer, 1920, 91 pp

Goldstein, K.: Über die aufsteigende Degeneration nach Querschnittsunterbrechung des Ruckenmarkes. (Tractus spino-cerebellaris posterior, Tractus spino-olivaris, Tractus spino-thalamicus.) *Neurol Zentralbl*, 29 898-911, 1910.

Goltz, F. Vagus und Herz. *Virchows Arch*, *26*:1-33, 1863.

Gooddy, W.: Sensation and volition. *Brain*, *72*:312-339, 1949.

Gordinier, H C The report of a case of occlusion of the left posterior inferior cerebellar artery. *J. Nerv & Ment Dis.*, *71*:1-6, 1930.

Gordon, G. and Whitteridge, D.: Conduction-time for human pain sensation. *Lancet*, *245*:700-701, 1943

Gordon, I R.S. and Tucker, J.F.: Lesions of the central nervous system in herpes zoster. *J Neurol., Neurosurg. & Psychiat.*, *8*:40-46, 1945.

Gowers, W.R. A case of unilateral gunshot injury to the spinal cord. *Trans. Clin. London*, 11 24-32, 1878

FRAZIER, C H. and RUSSELL, E.C.: Neuralgia of the face: An analysis of 754 cases with relation to pain and other sensory phenomena before and after operation. *Arch. Neurol. & Psychiat., 11*:557-563, 1924.

FRAZIER, C.H. and SPILLER, W.G.: Section of the anterolateral columns of the spinal cord (chordotomy). Discussion of the physiologic effects and clinical results in a series of eight cases. *Arch Neurol. & Psychiat., 9*:1-21, 1923.

FREEMAN, L.W. and HEIMBURGER, R.F.: Surgical relief of pain in paraplegic patients. *Arch. Surg., 55*.433-440, 1947.

FREEMAN, L W., SHUMACKER, H B., JR. and RADIGAN, L.R.: A functional study of afferent fibers in peripheral sympathetic nerves. *Surgery, 28*:274-281, 1950.

FREEMAN, W. and WATTS, J.W.: Pain mechanisms and the frontal lobes: A study of prefrontal lobotomy for intractable pain. *Ann. Int. Med., 28*:747-754, 1948.

FREEMAN, W and WATTS, J.W.: *Psychosurgery in the Treatment of Mental Disorders and Intractable Pain.* Springfield, Illinois, Thomas, 1950, 598 pp.

FRENCH, J.D.: Clinical manifestations of lumbar spinal arachnoiditis: A report of thirteen cases. *Surgery, 20*:718-729, 1946.

FRENCH, J.D., VON AMERONGEN, E.K. and MAGOUN, H.W.: An activating system in brain stem of monkey. *Arch. Neurol. & Psychiat*, *68* 577-590, 1952.

FRENCH, L.A. and PEYTON, W.T · Ipsilateral sensory loss following cordotomy. *J. Neurosurg*, 5.403-404, 1948.

von FREY, M.: Beitrage zur Physiologie des Schmerzsinns. *Berlin sachs. Ges. Wiss. math -phys. Kl., 46*:185-196, 283-296, 1894.

von FREY, M.: Beiträge zur Sinnesphysiologie der Haut. *Berlin sachs. Ges Wiss. math.-phys. Kl., 47*.166-184, 1895.

von FREY, M.: Untersuchungen über die Sinnesfunctionen der Menschlichen Haut. Erste Abhandlung: Druckempfindung und Schmerz. *Berlin sachs. Ges. Wiss. math.-phys. Kl., 48*:175-266, 1896.

von FREY, M.: Versuche uber schmerzerregende Reize. *Z. Biologie, 76*:1-24, 1922.

von FREY, M.: Der Schmerzsinn, Section VII (3) of chapter entitled "Physiologie der Haut" in *Pt. 2 of Vol. 1 of Handbuch der Haut und Geschlechts-Krankheiten*, Berlin, Springer, 1929, pp. 139-150.

FRYKHOLM, R.: Cervical nerve root compression resulting from disc degeneration and root-sleeve fibrosis. A clinical investigation *Acta chir scandinav., Suppl.* 160, 1951, 149 pp.

FULTON, J.F.: The frontal cortex and visceral pain. Presented at meeting of the Harvey Cushing Society, San Francisco, August 20, 1948.

FULTON, J.F. *Physiology of the nervous system*, 3rd ed., New York, Oxford University Press, 1949, 667 pp

FULTON, J.F.: The limbic system. A study of the visceral brain in primates and man. *Yale J. Biol. & Med., 26*:107-118, 1953

FULTON, J.F. and JACOBSEN, C.F.: The functions of the frontal lobes, a comparative study in monkeys, chimpanzees, and man. *Abstr. 2nd Int. Neurol. Cong., London*, 1935. 70-71.

FURLOW, L.T.: Discussion of paper by R. G. SPURLING and E. G. GRANTHAM: Glossopharyngeal neuralgia. *South. M. J., 35*.509-513, 1942.

FURLOW, L.T.: Tic douloureux of the nervus intermedius (so-called idiopathic geniculate neuralgia). *J.A.M.A*, *119*:255-259, 1942.

GAGE, M.: Discussion of paper by E J BROWDER and J. A. deVEER, Herpes zoster: A surgical procedure for the treatment of postherpetic neuralgia. *Ann. Surg., 130*.622-636, 1949.

GARDNER, E. and CUNEO, H.M.: Lateral spinothalamic tract and associated tracts in man. *Arch. Neurol. & Psychiat., 53*:423-430, 1945.

GARDNER, W.J.: Removal of the right cerebral hemisphere for infiltrating glioma. *J.A.M.A*, *101*.823-825, 1933.

GARDNER, W.J. and BABBITT, J.A.: *The occurrence of tympanic hemorrhage following radical* operation for the relief of trigeminal neuralgia. *Ann Otol. Rhinol. Laryngol*, *38*:1040-1045, 1929.

de GUTIÉRREZ-MAHONEY, C.G.: The treatment of painful phantom limb. A follow-up study. *Surg. Clin. North America*, 28:481-483, 1948.

GUTTMANN, L. and MEDAWAR, P.B.: The chemical inhibition of fibre regeneration and neuroma formation in peripheral nerves. *J. Neurol., Neurosurg. & Psychiat.*, 5:130-141, 1942.

HAGGQVIST, G.: Analyse der Faserverteilung in einem Rückenmarkquerschnitt (Th3). *Z. mikr.-anat. Forsch.*, 39:1-34, 1936.

HÄRTEL, F.[F.]: Die Behandlung der Trigeminusneuralgie mit intrakraniellen Alkoholeinspritzungen. *Deutsche Ztschr. Chir.*, 126:429-552, 1914.

HÄRTEL, F.F.: Zur Punktion des Ganglion Gasseri. *Zentralbl. Chir.*, 60:310-312, 1933.

HÄRTEL, F.F.: Roentgenologische Darstellung des Foramen ovale des Schädels und ihre Bedeutung für die Behandlung der Trigeminusneuralgie. *Deutsche med. Wchnschr.*, 61:1069-1072, 1935.

HALL, A.J. and EAVES, E.C.: Posterior inferior cerebellar thrombosis with unusual features. *Lancet*, 227:975-979, 1934.

HAMBY, W.B.: Trigeminal neuralgia due to radicular lesions. *Arch. Surg.*, 46:555-563, 1943.

HAMBY, W.B.: Trigeminal neuralgia due to contralateral tumors of the posterior cranial fossa. Report of 2 cases. *J. Neurosurg.*, 4:179-182, 1947.

HAMBY, W.B.: *Intracranial Aneurysms.* Springfield, Illinois, Thomas, 1952, 564 pp.

HAMBY, W.B., SHINNERS, B.M. and MARSH, I.A.: Trigeminal tractotomy. Observations on forty-eight cases. *Arch. Surg.*, 57:171-177, 1948.

HAMBY, W.B. and TERRY, R.N.: Air embolism in operations done in the sitting position. A report of five fatal cases and one of rescue by a simple maneuver. *Surgery*, 31:212-215, 1952.

HAMILTON, F.E. and HAYES, G.J.: Prefrontal lobotomy in the management of intractable pain. *Arch. Surg.*, 58:731-738, 1949.

HARDY, J.D. and OPPEL, T.W.: The thermal response of the skin to radiation. *Physics*, 7:466-479, 1936.

HARDY, J.D., WOLFF, H.G. and GOODELL, H.: The pain threshold in man. *Research Publ. A. Nerv. & Ment. Dis.*, 23:1-15, 1943.

HARRIS, W.: Alcohol injection of the Gasserian ganglion for trigeminal neuralgia. *Lancet*, 1:218-221, 1912.

HARRIS, W.: Persistent pain in lesions of the peripheral and central nervous system. *Brit. M. J.*, 2:896-900, 1921.

HARRIS, W.: *Neuritis and Neuralgia.* London, Oxford University Press, 1926, 418 pp.

HARRIS, W.: Sensory changes in spinal cord and medullary lesions. *Brain*, 50:399-412, 1927.

HARRIS, W.: *The Facial Neuralgias.* London, Oxford University Press, 1937, 109 pp.

HARRIS, W.: An analysis of 1433 cases of paroxysmal trigeminal neuralgia (trigeminal-tic) and the end-results of Gasserian alcohol injection. *Brain*, 63:209-224, 1940A.

HARRIS, W.: Alcohol injection of the Gasserian ganglion for migrainous neuralgia. *Lancet*, 239:481-482, 1940B.

HARRISON, F. and CORBIN, K.B.: Oscillographic studies on the spinal tract of the fifth cranial nerve. *J. Neurophysiol.*, 5:465-482, 1942.

HARTLEY, F.: Intracranial neurectomy of the second and third divisions of the fifth nerve. A new method. *New York M. J.*, 55:317-319, 1892.

HAVEN, H. and KING, R.L.: Section of the posterior roots for the relief of pain in angina pectoris. Observations in five cases. *Surg., Gynec. & Obst.*, 75:208-219, 1942.

HAWKES, C.D. and GOTTEN, N.: Prefrontal lobotomy vs. cordotomy for relief of intractable pain. *Tr. Am. Neurol. A.*, 208-210, 1948.

HAXTON, H.A.: Chemical sympathectomy. *Brit. M. J.*, 1:1026-1028, 1949.

HEAD, H. and CAMPBELL, A.W.: The pathology of herpes zoster and its bearing on sensory localization. *Brain*, 23:353-523, 1900.

HEAD, H. and HOLMES, G.: Sensory disturbances from cerebral lesions. *Brain*, 34:102-254, 1911.

HEAD, H. and HOLMES, G.: Researches into sensory disturbances from cerebral lesions. *Lancet*, 1:1-4, 1912.

GRANIT, R., LEKSELL, L and SKOGLUND, C.R.: Fibre interaction in injured or compressed region of nerve. *Brain*, *67*:125-140, 1944.

GRANT, F.C.: Value of cordotomy for the relief of pain. *Ann. Surg.*, *92* 998-1006, 1930.

GRANT, F.C.: Results with cordotomy for relief of intractable pain due to carcinoma of the pelvic organs. *Am. J. Obst. & Gynec.*, *24*.620-625, 1932.

GRANT, F C.: Alcohol injection in the treatment of major trigeminal neuralgia. *J.A.M.A*, *107*:771-773, 1936.

GRANT, F.C. Results in the operative treatment of major trigeminal neuralgia. *Ann. Surg.*, *107*:14-19, 1938

GRANT, F.C.: Surgical methods for relief of pain. *Bull. New York Acad. Med.*, *19*:373-385, 1943.

GRANT, F.C.: Complications accompanying surgical relief of pain in trigeminal neuralgia. *Am J. Surg.*, *75*.42-47, 1948.

GRANT, F.C, GROFF, R.A. and LEWY, F.H: Section of the descending spinal root of the fifth cranial nerve *Arch. Neurol. & Psychiat*, *43*:498-507, 1940.

GRANT, F C. and WEINBERGER, L.M: Experiences with intramedullary tractotomy. IV. Surgery of the brain stem and its operative complications. *Surg., Gynec. & Obst.*, *72*.747-754, 1941*A*.

GRANT, F.C. and WEINBERGER, L.M.: Experiences with intramedullary tractotomy. I. Relief of facial pain and summary of operative results. *Arch. Surg.*, *42*.681-692, 1941*B*.

GRANTHAM, E.G. Prefrontal lobotomy for relief of pain, with a report of a new operative technique. *J. Neurosurg*, *8*.405-410, 1951.

GRAY, H. *Anatomy of the Human Body*. 24th ed. Philadelphia and New York, Lea & Febiger, 1942, 1428 pp.

GREENHILL, J.P. and SCHMITZ, H.E.: Sympathectomy for intractable pain in inoperable cancer of the cervix. *J.A.M.A*, *101*.26-29, 1933.

GRIMSON, K S., HESSER, F.H. and KITCHIN, W.W.: Early clinical results of transabdominal celiac and superior mesenteric ganglionectomy, vagotomy, or transthoracic splanchnicectomy in patients with chronic abdominal visceral pain *Surgery*, *22*:230-238, 1947.

GROFF, R.A. and HOUTZ, S J. *Manual of Diagnosis and Management of Peripheral Nerve Injuries*. Philadelphia, Lippincott, 1945, 188 pp.

GROFF, R A. and LEWY, F.H.: Danger of subarachnoid injection of alcohol for relief of pain *Arch. Neurol. & Psychiat*, *45* 533-535, 1941.

GROVES, E W H.: On the division of the posterior spinal nerve roots: (1) for pain, (2) for visceral crises, (3) for spasm *Lancet*, *2*:79-85, 1911

GUIDETTI, B.. Tractotomy for the relief of trigeminal neuralgia: Observations in 124 cases *J. Neurosurg.*, *7*:499-508, 1950.

GUILLAIN, G. and BERTRAND, I.: La nécrose atrophique symétrique des circonvolutions pariétales ascendantes et des convolutions occipitales. Forme anatome-clinique encéphalique des ischémies nécrotiques symétriques des extremités. *Ann. Méd*, *31*.35-58, 1932.

GUILLAUME, J.: Myélotomie postérieure pour algies postzostériennes et moignons douloureux avec membres fantômes Remarques physio-pathologiques. *Rev. Neurol.*, *74* 317-319, 1942

GUILLAUME, J.: A propos de la neurotomie rétrogassérienne partielle. *Rev. Neurol*, *79*:199-201, 1947.

GUILLAUME, J, BERTRAND, I and MAZARS, G: Un cas de moignon douloureux traité par myélotomie. Étude electroencéphalographique et considérations physiopathologiques sur la douleur. *Rev. Neurol*, *77*:145, 1945.

GUILLAUME, J., de SÉZE, S. and MAZARS, G.. *Chirurgie cérébro-spinale de la douleur*. Paris, Presses Universitaires de France, 1949, 191 pp.

GUIOT, G: *Actualités de neuro-chirurgie*. Paris, Doin, 1948, 87 pp.

GUIOT, G. and FORJAZ, S.: La tractotomie mesencéphalique par voie sous-temporale *Rev. Neurol*, *79*:733-740, 1947.

GURD, F B.: Posttraumatic acute bone atrophy A clinical entity. *Arch. Surg.*, *32* 273-291, 1936

de GUTIÉRREZ-MAHONEY, C G The treatment of painful phantom limb by removal of post-central cortex. *J Neurosurg.*, *1*:156-162, 1944.

Horton, B.T., MacLean, A.R. and Craig, W.McK.: A new syndrome of vascular headache: Results of treatment with histamine. Preliminary report. *Proc. Staff Meet., Mayo Clin.*, 14:257-260, 1939.

Hovelacque, A.: *Anatomie des nerfs craniens et rachidiens et du système grand sympathique chez l'homme.* Paris, Doin, 1927, 873 pp.

Hovelacque, A. and Rouvière, J.: Note sur la disposition anatomique du rameau sensitif du conduit auditif externe et du rameau auriculaire postérieur du facial. *Bull. Soc. Anat. Paris*, 92:318-321, 1922.

Hun, H.: Analgesia, thermic anesthesia and ataxia, due to occlusion of left inferior posterior cerebellar artery. *New York M. J.*, 65:513-519, 613-620, 1897.

Hunt, J.R.: The sensory field of the facial nerve. A further contribution to the symptomatology of the geniculate ganglion. *Brain*, 38:418-446, 1915.

Hunter, C.R. and Mayfield, F.H.: Role of the upper cervical roots in the production of pain in the head. *Am. J. Surg.*, 78:743-751, 1949.

Hurst (formerly Hertz), A.F.: On the sensibility of the alimentary canal in health and disease. *Lancet*, *1*:1051-1056, 1119-1124, 1187-1193, 1911.

Hurwitz, A. and Gurwitz, J.: Relief of pain in chronic relapsing pancreatitis by unilateral sympathectomy. *Arch. Surg.*, *61*:372-378, 1950.

Hutter, F.: Über Neuralgien des Nervus laryngeus superior. *Mschr. Ohrenheilk.*, *63*:402-409, 1929.

Hyndman, O.R.: Post-herpetic neuralgia in the distribution of the cranial nerves: Evidence for sympathetic mediation and surgical care. *Arch. Neurol. & Psychiat.*, *42*:224-232, 1939.

Hyndman, O.R.: Tic douloureux. Relation of "trigger zones" to painful seizures. *Arch. Surg.*, *42*:913-916, 1941.

Hyndman, O.R.: Lissauer's tract section. A contribution to chordotomy for the relief of pain (preliminary report). *J. Internat. Coll. Surgeons*, *5*:394-400, 1942.

Hyndman, O.R.: Communication, 1947, cited by O. Sugar and P. C. Bucy in "Postherpetic trigeminal neuralgia." *Arch. Neurol. & Psychiat.*, *65*:131-145, 1951.

Hyndman, O.R.: Intractable pain due to cancer. *Am. J. Surg.*, *75*:187-199, 1948.

Hyndman, O.R. and Jarvis, F.J.: Gastric crisis of tabes dorsalis. Treatment by anterior chordotomy in eight cases. *Arch. Surg.*, *40*:997-1013, 1940.

Hyndman, O.R. and Van Epps, C.: Possibility of differential section of the spinothalamic tract. A clinical and histologic study. *Arch. Surg.*, *38*:1036-1053, 1939.

Hyndman, O.R. and Wolkin, J.: Anterior cordotomy. Further observations on physiologic results and optimum manner of performance. *Arch. Neurol. & Psychiat.*, *50*:129-148, 1943.

Hyslop, G.H.: Face pain. *New York State J. Med.*, *36*:91-95, 1936.

Ingersoll, F.M. and Meigs, J.V.: Presacral neurectomy for dysmenorrhea. *New England J. Med.*, *238*:357-360, 1948.

Inman, V.T. and Saunders, J.B. deC.M.: Referred pain from skeletal structures. *J. Nerv. & Ment. Dis.*, *99*:660-667, 1944.

Jacobsen, C.E., Braasch, W.F. and Love, J.G.: Presacral neurectomy for intractable vesical pain and neurogenic vesical dysfunction. *Surg., Gynec. & Obst.*, *79*:21-26, 1944.

Jefferson, G.: Observations on trigeminal neuralgia. *Brit. Med. J.*, *2*:879-883, 1931A.

Jefferson, G.: Glossopharyngeal neuralgia. *Lancet*, *221*:397-399, 1931B.

Jepson, E.: Quoted in "Annotations" entitled "Surgery for intermittent claudication" in *Lancet*, *254*:526-527, 1948.

Jimenez Gonzalez, L.: Topografia del "tractus spinalis nervi trigemini" en relacion con la operacion de la tractotomia. *Arch. esp. Morfol.*, *4*:23-67, 1944.

Johnson, D.A., Roth, G.M. and Craig, W.McK.: Orthostatic hypotension following chordotomy for intractable pain. *Proc. Staff Meet., Mayo Clin.*, *27*:131-135, 1952.

Jones, C.M. and Chapman, W.P.: Studies on the mechanism of the pain of angina pectoris with particular relation to hiatus hernia. *Tr. A. Am. Physicians*, *57*:139-151, 1942.

Jonnesco, T.: Angine de poitrine guérie par la résection du sympathique cervico-thoracique. *Bull. Acad. Méd. Paris*, *84*:93-102, 1920.

HEAD, H., RIVERS, W.H.R. and SHERREN, J.: The afferent nervous system from a new aspect. *Brain, 28*.99-115, 1905.

HEAD, H. and SHERREN, J.: The consequences of injury to the peripheral nerves in man. *Brain, 28*.116-338, 1905.

HÉCAEN, H., TALAIRACH, J, DAVID, M. and DELL, M.B.: Coagulations limitées du thalamus dans les algies du syndrome thalamique. *Rev. neurol., 81*:917-931, 1949.

HEINBECKER, P, BISHOP, G.H. and O'LEARY, J.: Analysis of sensation in terms of the nerve impulse. *Arch. Neurol & Psychiat, 31*.34-53, 1934.

HENDERSON, W.R. and SMYTH, G.E.: Phantom limbs. *J. Neurol., Neurosurg. & Psychiat.*, N.S *11*.88-112, 1948

HERRIN, R C. and MEEK, W.J.: Afferent nerves excited by intestinal distention. *Am. J. Physiol*, *144*·720-724, 1945.

HERZ, E and YAHR, M D.. Painful sensory syndrome during nerve regeneration. *Tr. Am. Neurol. A.*, 213-218, 1950.

HESS, E.: Renal sympathectomy. *Pennsylvania M. J*, *33*:741-747, 1930.

HESSE, E.: Über die chirurgische Behandlung der genuinen Glossopharyngeusneuralgie. *Verh. Russ. Chir. Trilogov. Ges.*, 1930. (Abstracted in *Int. Abst. Surg. Gynec. Obstet.*, *52*:114-115, 1931.)

HEUSNER, A.P.: Phantom genitalia. *Tr. Am. Neurol A.*, 128-131, 1950.

HIGHET, W.B.: Procaine nerve block in investigation of peripheral nerve injuries. *J. Neurol. & Psychiat., 5*:101-116, 1942.

HILL, C J.: A contribution to our knowledge of the enteric plexuses. *Philos. Tr., 215B*.355-387, 1927.

HILTON, J.: *Rest and Pain.* Cincinnati, P. W. Garfield, 1891, 504 pp.

HINGSON, R.A. and EDWARDS, W.B.: Continuous caudal analgesia in obstetrics *J. A. M. A*, *121*:225-229, 1943

HINSEY, J C.: Observations on the innervation of the blood vessels in skeletal muscle. *J. Comp. Neurol*, *47* 23-60, 1928.

HINSEY, J.C : Three types of fibers going to skeletal muscle and its blood vessels. *Research Publ A. Nerv & Ment. Dis., 9*:153-180, 1930.

HINSEY, J.C.. The anatomical relations of the sympathetic system to visceral sensation *Research Publ A. Nerv. & Ment. Dis*, *15*:105-180, 1935.

HIRSCHBOECK, F J. and GILLESPIE, M G . A complication of paravertebral injection of alcohol: Report of a case. *Arch. Neurol & Psychiat., 48*.320-322, 1942.

HOLBROOK, T.J. and de GUTIÉRREZ-MAHONEY, C.G : Diffusion of painful stimuli over segmental, infrasegmental, and suprasegmental levels of the spinal cord. *Federation Proc., 6*·131, 1947.

HOLDEN, W D. Sympathetic dystrophy. *Arch Surg*, *57*:373-384, 1948.

HOLLANDER, E.: A clinical gauge for sensitivity to pain. *J. Lab. & Clin. Med*, *24*.537-538, 1939

HOMANS, J : Minor causalgia: A hyperesthetic neurovascular syndrome. *New England J. M.*, *222* 870-874, 1940.

HOME, E . A short life of the author's life by his brother-in-law, Everard Home. Prefixed to Vol. I of J. HUNTER's *Treatise on the Blood, Inflammation, and Gunshot Wounds* Philadelphia, Thomas Bradford, 1796, (pp. i-lvi).

HOOVER, W.B. and POPPEN, J L.: Glossopharyngeal neuralgia. *J. A. M. A.*, *107*:1015-1017, 1936.

HORRAX, G . Experiences in cordotomy *Arch. Surg., 18*:1140-1164, 1929.

HORRAX, G.: Experiences with cortical excisions for the relief of intractable pain in the extremities. *Surgery, 20*.593-602, 1946.

HORRAX, G. and POPPEN, J.L.· Trigeminal neuralgia: Experiences with, and treatment employed in 468 patients during the past ten years. *Surg., Gynec. & Obst., 61*.394-402, 1935.

HORSLEY, V., TAYLOR, J. and COLMAN, W.S.: Remarks on the various surgical procedures devised for the relief or cure of trigeminal neuralgia (tic douloureux). *Brit. M. J., 2*:1139-1143, 1891A; *2*:1191-1193, 1891*B*, *2*:1249-1252, 1891*C*.

Kirschner, M.: Die Punktionstechnik und die Elektrokoagulation des Ganglion Gasseri. *Arch. klin. Chir.*, *176*:581-620, 1933.

Kirschner, M.: Zur Behandlung der Trigeminusneuralgie. Erfahrungen an 250 Fallen. *Arch. klin. Chir.*, *186*:325-334, 1936.

Kölliker, A.: *Handbuch der Gewebelehre des Menschen II Bd. Nervensystem des Menschen und der Thiere.* Leipzig, W. Englemann, 1896, 6th ed., 874 pp.

Kolb, L.C.: Psychiatric aspects of treatment for intractable pain in the phantom limb. *Med. Clin. North America*, *34*:1029-1041, 1950.

Kolb, L.C., Frank, L.M. and Watson, E.J.: Treatment of the acute painful phantom limb. *Proc. Staff Meet. Mayo Clin.*, *27*:110-118, 1952.

Koskoff, Y.D., Dennis, W., Lazovik, D. and Wheeler, E.T.: The psychological effects of frontal lobotomy performed for the alleviation of pain. *Research Publ. A. Nerv. Ment. Dis.*, *27*:723-753, 1948.

Kozol, H.L.: Thalamic dysfunction. Report of a case in which a thalamic syndrome was treated by excision of a porencephalic cyst. *Arch. Neurol. & Psychiat.*, *40*:352-361, 1938.

Krause, F.: The question of priority in devising a method for the performance of intra-cranial neurectomy in the fifth nerve. (Correspondence.) *Ann. Surg.*, *18*:362-364, 1893A.

Krause, F.: Entfernung des Ganglion Gasseri und des central davon gelegenen Trigeminusstammes. *Deutsche med. Wchnschr.*, *19*:341-344, 1893B.

Krause, G.R. and Lubert, M.: Ureteral compression due to metastasis from carcinoma of sigmoid. *J.A.M.A.*, *149*:1555-1557, 1952.

Krayenbühl, H. and Stoll, W.A.: Psychochirurgie bei unerträglichen Schmerzen. *Acta Neurochir.*, *1*:1-41, 1950A.

Krayenbühl, H. and Stoll, W.[A.]: La leucotomie préfrontale et la topectomie pour le traitement des douleurs irréductibles. *Rev. neurol.*, *83*:40-41, 1950B.

Kroll, F.W.: Schwellenuntersuchungen bei Läsionen der afferenten Leitungsbahnen. *Ztschr. ges. Neurol. & Psychiat.*, *128*:751, 776, 1930.

Kubanyi, E.: Sur le traitement de la nevralgie du nerf trijumeau par l'électrocoagulation intracranienne du ganglion de Gasser (d'apres 301 cas). *Lyon chir.*, *41*:681-689, 1946.

Kuhn, W.G.,Jr.: The care and rehabilitation of patients with injuries of the spinal cord and cauda equina. A preliminary report on 113 cases. *J. Neurosurg.*, *4*:40-68, 1947.

Kunkle, E.C. and Chapman, W.P.: Insensitivity to pain in man. *Research Publ. A. Nerv. & Ment. Dis.*, 23:100-109, 1943.

Kuntz, A. and Farnsworth, D.I.: Distribution of afferent fibers via the sympathetic trunks and gray communicating rami to the brachial and lumbosacral plexuses. *J. Comp. Neurol.*, 53:389-399, 1931.

Kuntz, A. and Morehouse, A.: Thoracic sympathetic cardiac nerves in man: Their relation to cervical sympathetic ganglionectomy. *Arch. Surg.*, *20*:607-613, 1930.

Kuntz, A. and Saccomanno, G.: Afferent conduction from extremities through dorsal root fibers via sympathetic trunks: Relation to pain in paralyzed extremities. *Arch. Surg.*, *45*:606-612, 1942.

Kuru, M.: *Sensory Paths in the Spinal Cord and Brain Stem of Man.* Tôkyo and Ôsaka, Sôgensya, 1949, 39 pp.

Kutner, R. and Kramer, F.: Sensibilitatsstorungen bei acuten und chronischen Bulbarerkrankungen (Zugleich Beitrage zur Kenntnis der Syringobulbie). *Arch. Psychiat. Nervenkr.*, *42*:1002-1060, 1907.

Labat, G.: *Regional Anesthesia: Its Technic and Clinical Application.* Philadelphia, W. B. Saunders Co., 1924, 496 pp.

Läwen, A.: Weitere Erfahrungen uber paravertebrale Schmerzaufhebung zur Differentialdiagnose von Erkrankungen der Gallenblase, des Magens, der Niere und des Wurmfortsatzes sowie zur Behandlung postoperative Lungenkomplikationen. *Zentralbl. Chir.*, *50*:461-465, 1923.

Landis, E.M.: Neuro-injection studies of capillary blood pressure in human skin. *Heart*, *15*:209-228, 1930.

JONNESCO, T.: *Le sympathique cervico-thoracique.* Paris, Masson, 1923, 91 pp.

JONNESCO, T. and ENARCHESCO, M.: Nerfs cardiaques naissant de la chaine thoracique du sympathique, au-dessous du ganglion stellaire. Les nerfs cardiaques thoraciques chez quelques mammifères. *Compt. rend. Soc. biol., Paris,* 97.977-980, 1927.

JUDOVICH, B. and BATES, W.. The pitcher plant distillate and the ammonium salts for relief of pain Chap 12 of *Segmental Neuralgia in Painful Syndromes,* Philadelphia, F. A. Davis Co., 1944, 313 pp.

KADANOFF, D: Beitrage zur Kenntnis der Nervenendigungen im Epithel der Saugetiere. *Z. Anat. EntwGesch*, *73:*431-452, 1924.

KADANOFF, D.: Beitrage zur Kenntnis der intraepithelialen Nerven des Menschen II. Die Nerven in Epithel der Epiglottisschleimhaut. *Ztschr. Zellforsch. u. mikr. Anat., 6.*337-341, 1927

KADANOFF, D. Uber die intraepithelialen Nerven und ihre Endigungen beim Menschen und bei den Saugetieren. *Ztschr. Zellforsch. u. mikr. Anat., 7.*553-576, 1928.

KAHN, E.A.: Anterolateral chordotomy for intractable pain. *J.A.M.A., 100:*1925-1928, 1933.

KAHN, E.A. and BARNEY, B F.: Anterolateral chordotomy for intractable pain of tabes dorsalis. *Arch. Neurol & Psychiat., 38:*467-472, 1937.

KAHN, E.A. and PEET, M.M. The technique of anterolateral cordotomy. *J. Neurosurg*, *5.*276-283, 1948.

KAHN, E A and RAND, R W.. On the anatomy of anterolateral cordotomy. *J. Neurosurg*, *9.*611-619, 1952.

KALLIO, K E.: Permanency of the results obtained by sympathetic surgery in the treatment of phantom pain. *Acta orthop scandinav., 19.*391-397, 1950.

KAPLAN, E B.. Obturator nerve avulsion in the treatment of painful hip joints. *Surg Clin. North America, 28.*473-480, 1948.

KAPPIS, M.. Weitere Erfahrungen mit der Sympathektomie *Klin Wchnschr*, *2.*1441-1446, 1923.

KARNOSH, L.J., GARDNER, W J. and STOWELL, A.: Glossopharyngeal neuralgia: Physiologic considerations of the role of the ninth and tenth cranial nerves. *Tr. Am. Neurol. A*, 205-207, 1947.

KARPLUS, I P, and KREIDL, A. Zur Kenntnis der Schmerzleitung im Ruckenmark II. Mitteilung. *Pflug. Arch ges Physiol*, *207:*134-139, 1925.

KATZ, B and SCHMITT, O H.: Electric interaction between two adjacent nerve fibres. *J. Physiol*, *97*·471-488, 1940

KEEGAN, J.J: Dermatome hypalgesia associated with herniation of intervertebral disc. *Arch. Neurol. & Psychiat., 50.*67-83, 1943.

KEEGAN, J.J.: Dermatome hypalgesia with posterolateral herniation of lower cervical intervertebral disc. *J Neurosurg., 4.*115-139, 1947.

KELLGREN, J.H · On the distribution of pain arising from deep somatic structures with charts of segmental pain areas *Clin. Sc*, *4.*35-46, 1939

KELLGREN, J H.: Somatic simulating visceral pain. *Clin. Sc., 4* 303-309, 1940.

KENDALL, D: Some observations on central pain. *Brain, 62.*253-273, 1939.

KENDRICK, W, JOUSSE, A, SCOTT, J and BOTTERELL, H: Some autonomic responses in paraplegia. Presented at meeting of American Academy of Neurological Surgery, Houston, Texas, October, 1951

KENNEDY, F., EFFRON, A S. and PERRY, G The grave spinal cord paralyses caused by spinal anesthesia *Surg., Gynec. & Obst*, *91* 385-398, 1950.

KEY, J A. and REYNOLDS, F. C.: Intrapelvic obturator neurectomy for the relief of chronic arthritis of the hip *Surgery, 24* 959-967, 1948

KINSELLA, V.J.: *The Mechanism of Abdominal Pain* Sydney, Australasian Medical Publishing Co, Ltd., 1948, 230 pp.

KIRKLIN, J.W., CHENOWETH, A.I and MURPHEY, F Causalgia. A review of its characteristics, diagnosis, and treatment. *Surgery, 21:*321-342, 1947.

KIRSCHNER, M.: Zur Elektrochirurgie. *Arch klin Chir., 167.*761-768, 1931.

LERICHE, R.: Des migraines fronto-orbitaires: *Leur traitement par l'injection de novocaine* autour de l'artère temporale superficielle. *Progr. méd.*, June 10, 1913.

LERICHE, R.: *La chirurgie de la douleur.* 3rd ed., Paris, Masson, 1949, 471 pp.

LERICHE, R. and FONTAINE, R.: L'anesthésie isolée du ganglion étoilé: Sa technique, ses indications, ses résultats. *Presse méd.*, *12*,849-850, 1934.

LERICHE, R. and FONTAINE, R.: Les séquelles trophiques et douloureuses des traumatismes de la main et des doigts. Rapport présenté à l'occasion du VII[e] Congrès International des Accidents et des Maladies du Travail, Bruxelles, 22-26 Juillet, 1935.

LÉTIÉVANT, J.J.E.: *Traité des sections nerveuses: Physiologie pathologique, indications, procédés opératoires.* Paris, Baillière, 1873, 518 pp.

LEVINE, J., GREENBLATT, M. and SOLOMON, H.C.: Bimedial lobotomy: Its superiority over the conventional approach. *New England J. Med.*, *245*:888-891, 1951.

LÉVY, F. and BAUDOUIN, A.: Les injections profondes dans le traitement de la névralgie faciale rebelle. *Presse méd.*, *13*:108, 1906.

LEWIN, W. and PHILLIPS, C.G.: Observations on partial removal of the postcentral gyrus for pain. *J. Neurol., Neurosurg. & Psychiat.*, *15*:143-147, 1952.

LEWINSKY, W. and STEWART, D.: The innervation of the dentine. *J. Anat., London*, *70*:349-353, 1936.

LEWIS, T.: The effect of asphyxia and cocaine on nerves belonging to the nocifensor system. *Clin. Sc.*, *3*:59-65, 1937.

LEWIS, T.: *Pain.* New York, Macmillan, 1942, 192 pp.

LEWY, F.H. and GRANT, F.C.: Physiopathologic and pathoanatomic aspects of major trigeminal neuralgia. *Arch. Neurol. & Psychiat.*, *40*:1126-1134, 1938.

LHERMITTE, J. and NICOLAS: Les lésions spinales du zona: La myélite zostérienne. *Rev. neurol.*, *1*:361-364, 1924.

LHERMITTE, J. and PUECH, P.: L'algo-hallucinose des amputés Traitement par la résection du névrome, l'infiltration de la chaine sympathique, une double myélotomie postérieure, la résection du lobule pariétal superieur. *Rev. Neurol.*, *78*:33-35, 1946.

LHERMITTE, J. and VERMÈS, V.: Les lésions du système nerveux centrale dans la zona. *Rev. neurol.*, *1*:1231-1236, 1930.

LI, C.-L. and ELVIDGE, A.R : Observations on phantom limb in a paraplegic patient. *J. Neurosurg*, *8*:524-527, 1951.

LIBMAN, E.: Observations on sensitiveness to pain. *Tr. A. Am. Physicians*, *41*:305-308, 1926.

LIDZ, T. and PAYNE, R.L.,JR.: Causalgia: Report of recovery following relief of emotional stress. *Arch. Neurol. & Psychiat.*, *53* 222-225, 1945.

LINDGREN, I. and OLIVECRONA, H.: Surgical treatment of angina pectoris. *J. Neurosurg.*, *4*:19-39, 1947.

LIVINGSTON, K E.: The phantom limb syndrome. A discussion of the role of major peripheral nerve neuromas. *J. Neurosurg.*, *2*:251-255, 1945.

LIVINGSTON, W.K : Phantom limb pain. A report of ten cases in which it was treated by injections of procaine hydrochloride near the thoracic sympathetic ganglions *Arch. Surg.*, *37*:353-370, 1938

LIVINGSTON, W.K.: *Pain Mechanisms: A Physiologic Interpretation of Causalgia and its Related States* New York, Macmillan, 1943, 253 pp.

LOVE, J G Diagnosis and surgical treatment of glossopharyngeal neuralgia. *Surg. Clin. North America*, *24*.959-962, 1944.

LOVE, J G and ADSON, A W : Effect of cervicothoracic sympathectomy on headaches. *Arch. Neurol & Psychiat*, *35*:1203-1207, 1936.

LOVE, J G and WOLTMAN, H.W.: Trigeminal neuralgia and tumours of the Gasserian ganglion. *Proc Staff Meet., Mayo Clin.*, *17*:256-261, 1942.

LUDIN, M Über Thrombose der Arteria vertebralis. *Deutsche Ztschr. Nervenh*, *40*.380-386, 1910

LUNDY, J S · *Clinical Anesthesia. A Manual of Clinical Anesthesiology.* Philadelphia, Saunders, 1942, 771 pp

LANGLEY, J.N.: The autonomic nervous system. *Brain, 26:*1-26, 1903.

LANGLEY, J.N.: *The Autonomic Nervous System. Part I.* Cambridge, W. Heffer & Sons, 1921, 80 pp.

LANIER, L H . An experimental study of cutaneous innervation. *Research Publ. A. Nerv. & Ment. Dis*, *15*.437-456, 1935.

LANIER, L.H, CARNEY, H.M. and WILSON, W.D.. Cutaneous innervation. An experimental study. *Arch. Neurol. & Psychiat., 34:*1-60, 1935.

von LANZ, T. and CALVER, P.: Quoted in *Praktische Anatomie: Ein Lehr- und Hilfsbuch der anatomischen Grundlagen arztlichen Handelns* by T. von LANZ and W. WACHSMUTH, Berlin, Springer, 1938, 485 pp.

LAVRENKO, V.V.: Participation of sympathetic nerve fibers in the structure of sensory nerve endings *Bulletin of Experimental Biology and Medicine, U. S. S. R.*, *5* 37-38, 1938 (title and name of journal translated from Russian).

LEARMONTH, J R.: Neurosurgery in the treatment of diseases of the urinary bladder. I. Anatomic and surgical considerations. *J. Urol.*, *25*·531-549, 1931*A*.

LEARMONTH, J.R.: Neurosurgery in the treatment of diseases of the urinary bladder. II. Treatment of vesical pain. *J. Urol.*, *26*·13-24, 1931*B*.

LEARMONTH, J R. and BRAASCH, W.F.· Clinical and surgical aspects of nerve lesions involving the lower part of the urinary tract. *Ztschr. urol. Chir.*, *36*·195-201, 1933.

Le BEAU, J Experience with topectomy for the relief of intractable pain. *J. Neurosurg.*, *7* 79-91, 1950

Le BEAU, J.: Sur les fonctions du lobe préfrontal: Étude du syndrome postopératoire dans 132 topectomies et leucotomies partielles *Rev. Neurol.*, *85*.3-16, 1951.

LE BEAU, J and DAUM, S.: Chirurgie de la douleur: Tractotomies bulbaires et protubérantielles *IV^e Congr neurol int*, *3*.341-342, 1949.

Le BEAU, J., DAUM, S. and FORJAZ, S.. Les tractotomies trigéminales dans le traitement des névralgies faciales. *Brasil Médico-cirúrgico, 10:*331-344, 1948.

Le BEAU, J. and ROSIER, M Chirurgie des douleurs irréductibles: Résection de certaines aires préfrontales (topectomie). *IV^e Congr. neurol int., 3:*338-340, 1949.

LEE, F C : Meralgia paraesthetica. *Internat Clin*, *s.46, 1*.211-230, 1936.

LEHMANN, W Über sensible Fasern der vorderen Wurzeln mit besonderer Berucksichtigung der traumatischen Wurzelausreissungen. *Arch. klin. Chir*, *129:*252-280, 1924*A*.

LEHMANN, W.: Über die sensiblen Fasern der vorderen Wurzeln. *Klin. Wchnschr.*, *3*.1895-1898, 1924*B*

LEIGHTON, W.F Section of the anterolateral tract of the cord for the relief of intractable pain due to spinal cord lesions. *Surg, Gynec & Obst.*, *33*.246-249, 1921.

LEMMON, W.T. A method for continuous spinal anesthesia: A preliminary report. *Ann. Surg*, *111*·141-144, 1940

LEMOYNE, J.: Traitement de la névralgie, faciale essentielle par alcoolisation du ganglion de Gasser avec contrôle radiographique. *Rev stomatol.*, *47*.73-79, 1946.

LENNANDER, K.G Über die Sensibilitat der Bauchhohle und uber locale und allgemeine Anasthesie bei Bruch- und Bauchoperationen. *Zentralbl. Chir.*, *28* 209-223, 1901.

LENSHOEK, C.H . Excision of parietal cortex for phantom limb pain. *IV^e Congr. neurol int.*, *2:*52-53, 1949.

LERICHE, R.: *De l'élongation et de la section des nerfs périvasculaires dans certains syndromes* douloureux d'origine artérielle et dans quelques troubles trophiques *Lyon chir.*, *10*.378-382, 1913.

LERICHE, R.: Du traitement de la douleur dans les cancers abdominaux et pelviens inopérables ou récidivés. *Gaz. Hôp*, *109* 917-922, 1936.

LERICHE, R · *La chirurgie de la douleur.* 1st ed , Paris, Masson, 1937*A*, 428 pp.

LERICHE, R.: Des douleurs provoqués *par l'excitation du bout central des grands splanchniques* (douleurs cardiaques, douleurs pulmonaires) au cours des splanchnicotomies. *Presse méd*, *45*.971-972, 1937*B*.

LERICHE, R.: Des migraines fronto-orbitaires: Leur traitement par l'injection de novocaine autour de l'artère temporale superficielle. *Progr. méd.*, June 10, 1943.
LERICHE, R.: *La chirurgie de la douleur.* 3rd ed., Paris, Masson, 1949, 471 pp.
LERICHE, R. and FONTAINE, R.: L'anesthésie isolée du ganglion étoilé: Sa technique, ses indications, ses résultats. *Presse méd.*, 42:849-850, 1934.
LERICHE, R. and FONTAINE, R.: Les séquelles trophiques et douloureuses des traumatismes de la main et des doigts. Rapport présenté à l'occasion du VII[e] Congrès International des Accidents et des Maladies du Travail, Bruxelles, 22-26 Juillet, 1935.
LÉTIEVANT, J.J.E.: *Traité des sections nerveuses. Physiologie pathologique, indications, procédés opératoires.* Paris, Baillière, 1873, 548 pp.
LEVINE, J., GREENBLATT, M. and SOLOMON, H.C.: Bimedial lobotomy: Its superiority over the conventional approach. *New England J. Med.*, 245:888-891, 1951.
LEVY, F. and BAUDOUIN, A.: Les injections profondes dans le traitement de la névralgie faciale rebelle. *Presse méd.*, 13:108, 1906.
LEWIN, W. and PHILLIPS, C.G.: Observations on partial removal of the postcentral gyrus for pain. *J. Neurol., Neurosurg. & Psychiat.*, 15:143-147, 1952.
LEWINSKY, W. and STEWART, D.: The innervation of the dentine. *J. Anat., London*, 70:349-353, 1936.
LEWIS, T.: The effect of asphyxia and cocaine on nerves belonging to the nocifensor system. *Clin. Sc.*, 3:59-65, 1937.
LEWIS, T.: *Pain.* New York, Macmillan, 1942, 192 pp.
LEWY, F.H. and GRANT, F.C.: Physiopathologic and pathoanatomic aspects of major trigeminal neuralgia. *Arch. Neurol. & Psychiat.*, 40:1126-1134, 1938.
LHERMITTE, J. and NICOLAS: Les lésions spinales du zona: La myélite zostérienne. *Rev. neurol.*, 1:361-364, 1924.
LHERMITTE, J. and PUECH, P.: L'algo-hallucinose des amputés. Traitement par la resection du névrome, l'infiltration de la chaine sympathique, une double myélotomie postérieure, la résection du lobule pariétal supérieur. *Rev. Neurol.*, 78:33-35, 1946.
LHERMITTE, J. and VERMÈS, V.: Les lésions du système nerveux centrale dans la zona. *Rev. neurol.*, 1:1231-1236, 1930.
LI, C.-L. and ELVIDGE, A.R.: Observations on phantom limb in a paraplegic patient. *J. Neurosurg.*, 8:524-527, 1951.
LIBMAN, E.: Observations on sensitiveness to pain. *Tr. A. Am. Physicians*, 41:305-308, 1926.
LIDZ, T. and PAYNE, R.L.,JR.: Causalgia: Report of recovery following relief of emotional stress. *Arch. Neurol. & Psychiat.*, 53:222-225, 1945.
LINDGREN, I. and OLIVECRONA, H.: Surgical treatment of angina pectoris. *J. Neurosurg.*, 4:19-39, 1947.
LIVINGSTON, K.E.: The phantom limb syndrome. A discussion of the role of major peripheral nerve neuromas. *J. Neurosurg.*, 2:251-255, 1945.
LIVINGSTON, W.K.: Phantom limb pain. A report of ten cases in which it was treated by injections of procaine hydrochloride near the thoracic sympathetic ganglions. *Arch. Surg.*, 37:353-370, 1938.
LIVINGSTON, W.K.: *Pain Mechanisms: A Physiologic Interpretation of Causalgia and its Related States.* New York, Macmillan, 1943, 253 pp.
LOVE, J.G.: Diagnosis and surgical treatment of glossopharyngeal neuralgia. *Surg. Clin. North America*, 24:959-962, 1944.
LOVE, J.G. and ADSON, A.W.: Effect of cervicothoracic sympathectomy on headaches. *Arch. Neurol. & Psychiat.*, 35:1203-1207, 1936.
LOVE, J.G. and WOLTMAN, H.W.: Trigeminal neuralgia and tumours of the Gasserian ganglion. *Proc. Staff Meet., Mayo Clin.*, 17:256-261, 1942.
LÜDIN, M.: Über Thrombose der Arteria vertebralis. *Deutsche Ztschr. Nervenh.*, 40:380-386, 1910.
LUNDY, J.S.: *Clinical Anesthesia. A Manual of Clinical Anesthesiology.* Philadelphia, Saunders, 1942, 771 pp.

LYERLY, J.G.: Transsection of the deep association fibers of the prefrontal lobes in certain mental disorders. *South. Surgeon*, 8.426-434, 1939.

LYERLY, J.G.. Prefrontal lobotomy for the relief of intractable pain. Am. J. Surg, 81:526-532, 1951.

MACFARLANE, W.V.. Causalgic syndromes. *Australian New Zeal. J. Surg.*, *18*:191-208, 1949.

MCKECHNIE, R.E.. Sympathectomy for tic douloureux. *Canad. M. A. J.*, 28:41-42, 1933.

MCKEEVER, F.M.: A discussion of controversial points in amputation surgery. *Surg., Gynec. & Obstet*, *82*:495-511, 1946.

MACKENZIE, J.: *Angina Pectoris.* New York, Oxford University Press, 1924, 253 pp.

MCKENZIE, K.G.. Intracranial division of the vestibular portion of the auditory nerve for Menière's disease. *Canad. M.A.J.*, *34*:369-381, 1936.

MCKENZIE, K G.: Discussion of paper presented by W. S. KEITH on "Glossopharyngeal neuralgia. Recurrence after intracranial section of nerve," at meeting of Harvey Cushing Society, Memphis, Tenn., April, 1938. See abstract in *Zentralbl. Neurochir.*, *3*:354, 1938.

MCKENZIE, K.G : Medullary trigeminal tractotomy for tic douloureux Presented at meeting of New York Academy of Medicine, Feb. 17, 1953.

MCKINLEY, W.A. and MAGOUN, H.W.: The bulbar projection of the trigeminal nerve. *Am. J. Physiol.*, *137*:217-224, 1942A.

MCKINLEY, W.A. and MAGOUN, H.W.: The termination of ascending trigeminal and spinal tracts in the thalamus of the cat. *Am. J. Physiol*, *137*·409-416, 1942*B*.

MACLEAN, P.D : Psychosomatic disease and the "visceral brain." Recent developments bearing on the Papez theory of emotion. *Psychosom. Med.*, 11.338-353, 1949.

MCLELLAN, A M. and GOODELL, H.: Pain from the bladder, ureter and kidney pelvis. *Research Publ A. Nerv. & Ment Dis*, 23.252-262, 1943.

MCMURRAY, G A : Experimental study of a case of insensitivity to pain. *Arch. Neurol. & Psychiat.*, 64.650-657, 1950

MAGOUN, H.W : An ascending reticular activating system in the brain stem. *Arch Neurol. & Psychiat.*, 67.145-154, 1952

MALLET-GUY, P.: Les dystonies biliaires. *Rev. méd. Moyen-Orient, No.* 4.427-449, 1949.

MALLET-GUY, P and BEZES, H.· Réinterventions pour "récidive" après cholécystectomie. Technique et résultats. *Lyon chir.*, *44*:419-434, 1949.

MALLET-GUY, P., BLONDET, P. and DESLOUS, J . Le syndrome d'hypotomie de la voie biliaire principale *Arch Mal. App digest*, 38.383-400, 1949.

MALLET-GUY, P. and FEROLDI, J.. Le facteur "névrome d'amputation" dans le mécanisme de certaines récidives après cholécystectomie *Mém. Acad. Chir.*, 76·123-128, 1950

MALLET-GUY, P, FEROLDI, J. and MICEK, F. Maladie du sphincter d'Oddi Analyse de 70 observations recueillies du 12-7-45 au 7-5-49 II. Documents physiopathologiques, cliniques et thérapeutiques. *Lyon chir*, 45.181-199, 1950.

MALLET-GUY, P. and JAUBERT de BEAUJEU, M Treatment of chronic pancreatitis by unilateral splanchnicectomy *Arch Surg*, *60* 233-241, 1950.

MALLET-GUY, P., JEANJEAN, R. and SERVETTAZ, P Résultats éloignés de la splanchnicectomie unilatérale dans le traitement des pancréatites chroniques. *Lyon chir*, *40*.293-314, 1945.

MANDL, F.: Die Anwendungsbreite der paravertebralen Injektion *Klin Wchnschr.*, 4.2356-2358, 1925A.

MANDL, F.: Weitere Erfahrungen mit der paravertebralen Injektion bei der Angina pectoris *Wien. klin. Wchnschr.*, *38* 759-760, 1925*B*.

MANDL, F.: Die Wirkung der paravertebralen Injektion bei "Angina pectoris." *Arch. klin. Chir*, 136.495-518, 1925C

MANSUY, L., LECUIRE, J. and ACASSAT, L : Technique de la myélotomie commissurale postérieure. *J. Chir*, *60* 206-213, 1944

MARSHALL, J.: Sensory disturbances in cortical wounds with special reference to pain *J Neurol., Neurosurg. & Psychiat.*, *14*.187-204, 1951.

MARTIN, L. and DIEZ CANSECO, J.: *Pancreatic calculosis. J.A.M A*, *135*:1055-1060, 1947.

MAYFIELD, F.H.: *Causalgia* Springfield, Illinois, Thomas, 1951, 65 pp.

Mayfield, F.H. and Devine, J.W.: Causalgia. *Surg., Gynec. & Obst.*, 80:631-635, 1945.

Mayfield, F.H. and Hunter, C.: The role of the cervical roots in the production of pain in the head and face. Presented at meeting of American Academy of Neurological Surgery, New York, Sept. 30, 1952.

Meigs, J.V.: Excision of the superior hypogastric plexus (presacral nerve) for primary dysmenorrhea. *Surg., Gynec. & Obst.*, 68:723-732, 1939.

Meirowsky, A.M. and Pitto, F.F.: Surgical history of trigeminal neuralgia. *Arch. Neurol. & Psychiat.*, 49:574-580, 1943.

Meyer, A.W.: Verlaufen sensible Fasern in den vorderen Wurzeln. *Zentralbl. Chir.*, 48:1790-1793, 1921.

Meyer, A.W.: Über die fraglichen sensiblen Fasern der vorderen Wurzeln. (Eine kritische, experimentelle und klinische Studie.) *Deutsch. Ztschr. Chir.*, 199:38-65, 1926.

Michailow, S.: Über die sensiblen Nervenendigungen in der Harnblase der Säugetiere. *Arch. mikr. Anat.*, 71:254-283, 1908.

Michelsen, J.J.: Subjective disturbances of the sense of pain from lesions of the cerebral cortex. *Research Publ. Nerv. & Ment. Dis.*, 23:86-99, 1943.

Miles, H.H., Cobb, S. and Shands, H.C.: *Case Histories in Psychosomatic Medicine.* New York, Norton, 1952, 306 pp.

Miller, D.S. and de Takats, G.: Posttraumatic Dystrophy of the Extremities: Sudeck's Atrophy. *Surg., Gynec. & Obstet.*, 75:558-582, 1942.

Mills, C.K.: Preliminary note on a new symptom complex due to lesion of the cerebellum and cerebello-rubro-thalamic system. *J. Nerv. & Ment. Dis.*, 39:73-76, 1912.

Mills, C.K.: Discussion of paper on "Central pain from lesions of the pons" by T.H. Weisenburg and S.S. Stack, *Arch. Neurol. & Psychiat.*, 10:500-511, 1923.

Mitchell, G.A.G.: The innervation of the distal colon. *Edinburgh M. J.*, 42:11-20, 1935A.

Mitchell, G.A.G.: The innervation of the kidney, ureter, testicle and epididymis. *J. Anat.*, 70:10-32, 1935B.

Mitchell, G.A.G.: The nerve supply of the gastro-esophageal junction. *Brit. J. Surg.*, 26:333-345, 1938A.

Mitchell, G.A.G.: The innervation of the ovary, uterine tube, testis and epididymis. *J. Anat.*, 72:508-517, 1938B.

Mitchell, G.A.G.: A macroscopic study of the nerve supply of the stomach. *J. Anat.*, 75:50-63, 1940.

Mitchell, G.A.G.: *Anatomy of the Autonomic Nervous System.* Edinburgh and London, Livingstone, 1953, 356 pp.

Mitchell, J.K.: *Remote Consequences of Injuries of Nerves and their Treatment.* Philadelphia, Lea, 1895, 245 pp.

Mitchell, S.W.: Phantom limbs. *Lippincott's Mag. pop. Lit. Sci.*, 8:563-569, 1871.

Mitchell, S.W.: *Injuries of Nerves and Their Consequences.* Philadelphia, Lippincott, 1872, 377 pp.

Mitchell, S.W., Morehouse, G.R. and Keen, W.W.: *Gunshot Wounds and Other Injuries of Nerves.* Philadelphia, Lippincott, 1864, 164 pp.

Mixter, W.J. and White, J.C.: Pain pathways in the sympathetic nervous system: Clinical evidence. *Arch. Neurol. & Psychiat.*, 25:986-997, 1931.

Molitch, M. and Wilson, G.: Brown-Séquard paralysis following a paravertebral alcohol injection for angina pectoris. *J.A.M.A.*, 97:247, 1931.

Moniz, E.: *Tentatives opératoires dans le traitement de certaines psychoses.* Paris, Masson, 1936, 248 pp.

Moore, R.M. and Moore, R.E.: Studies on the pain-sensibility of arteries. I. Some observations on the pain sensibility of arteries. *Am. J. Physiol.*, 104:259-266, 1933.

Moore, R.M. and Singleton, A.O., Jr.: Studies on the pain-sensibility of arteries. II. Peripheral paths of afferent neurones from the arteries of the extremities and of the abdominal viscera. *Am. J. Physiol.*, 104:267-275, 1933.

MORISON, R.S. and DEMPSEY, E.W.: A study of thalamo-cortical relations. *Amer. J. Physiol*, *135*:281-292, 1942.

MORLEY, J.: *Abdominal Pain*. New York, Wood, 1931, 191 pp.

MORTON, D.R., KLASSEN, K.P. and CURTIS, G.M.: The effect of high vagus section upon the clinical physiology of the bronchus. *Tr. Am. Neurol. A.*, 143-145, 1950.

MORTON, D.R., KLASSEN, K.P. and CURTIS, G.M.: The clinical physiology of the human bronchi. II. The effect of vagus section upon pain of tracheobronchial origin. *Surgery, 30*.800-809, 1951.

MOTT, F.W.: Ascending degeneration resulting from lesions of the spinal cord in monkeys *Brain, 15* 215-229, 1892

MULLER, W.: *Beitrage zu pathologischen Anatomie und Physiologie des menschlichen Ruckenmarks.* Leipzig, Leopold Voss, 1871, 41 pp.

MURPHEY, F.: Discussion of paper by F. H MAYFIELD and C. HUNTER on "The role of the cervical roots in the production of pain in the head and face," presented at meeting of American Academy of Neurological Surgery, New York, Sept. 30, 1952.

NAFE, J.P and WAGONER, K.S: The insensitivity of the cornea to heat and pain derived from high temperatures *Am. J. Psychol., 49*.631-635, 1937.

NATHAN, P.W. and SMITH, M C: The centripetal pathway from the bladder and urethra within the spinal cord *J Neurol, Neurosurg. & Psychiat., 14* 262-280, 1951.

NESBIT, R.M.: Anterolateral chordotomy for refractory interstitial cystitis with intractable pain. *J. Urol*, *57*:741-745, 1947.

NESBIT, R.M. and MCLELLAN, F.C.: Sympathectomy for the relief of vesical spasm and pain resulting from intractable bladder infection. *Surg, Gynec. & Obst., 68*:540-546, 1939.

NICOLESCO, J.: A propos de la somatotopie des relais de la sensibilité générale au niveau du thalamus et surtout des noyaux en rapport avec la sensibilité de la face. *Compt rend Soc. biol, Paris, 115*:1556, 1934.

NIELSEN, J.M: Gerstmann syndrome. Finger agnosia, agraphia, confusion of right and left and acalculia: Comparison of this syndrome with disturbance of body scheme resulting from lesions of the right side of the brain. *Arch Neurol. & Psychiat., 39* 536-560, 1938.

NORTHFIELD, D.W C. Some observations on headache. *Brain, 61*:133-162, 1938.

NULSEN, F: Data presented at meeting of Society of Neurological Surgeons in Philadelphia, June, 1952.

OBERSTEINER, H.: *Anleitung beim Studium des Baues der nervosen Zentralorgane im gesunden und kranken Zustande* Leipzig and Vienna, F. Deuticke, 1912, 764 pp.

ODDSSON, B. Electrocoagulation of the Gasserian ganglion by the Kirschner method *Acta psychiat, Kbh., 19* 293-299, 1944.

ODOM, G.L. and LYMAN, R S.: Speech disorder following excision of postcentral gyrus. *Tr Am Neurol. A.*, 67-70, 1946

OKONEK, G. Neuralgie des N. intermedius (Ramsay Hunt). Retroganglionare Wurzeldurchschneidung nach Taylor *Zentralbl. Neurochir., 11*.211-221, 1951.

OLDBERG, E.: Chordotomy. *Surg. Clin. North America, 12*:1315-1322, 1932.

OLIVECRONA, H The syndrome of painful anaesthesia following section of the sensory root of the fifth nerve in tic douloureux. *Acta chir. scandinav., 82*.99-106, 1939.

OLIVECRONA, H Tractotomy for relief of trigeminal neuralgia. *Arch Neurol. & Psychiat., 47*.544-564, 1942

OLIVECRONA, H Notes on the surgical treatment of migraine. *Acta med scandinav., 128* 229-238 (Suppl. 196), 1947A.

OLIVECRONA, H · The surgery of pain *Acta psychiat, Kbh., Suppl 46,* 1947B.

OLSEN, C.W.: Injury to the spinal cord and spinal nerve roots in the course of paravertebral injection. *Bull. Los Angeles Neurol. Soc., 6*:131-134, 1941.

OLSZEWSKI, J.: On the anatomical and functional organization of the spinal trigeminal nucleus *J. Comp Neurol*, 92.401-409, 1950.

PAGE, I. H. and HEUER, G J.: Treatment of essential and malignant hypertension by section of anterior nerve roots. *Arch Int. Med., 59*.245-298, 1937.

PAGET, J.: Clinical lecture on some cases of local paralysis, delivered at St. Bartholomew's Hospital, on February 6, 1864. *Med. Times and Gaz.*, *1*:331-332, 1864.

PAPEZ, J.W.: A proposed mechanism of emotion. *Arch. Neurol. & Psychiat.*, *38*:725-743, 1937.

PARÉ, A.: *La maniere de traicter les playes faictes tat par hacquebutes, et cetera.* Paris, Iean de Brie, 1551.

PARÉ, A.: Histoire de defunct Roy Charles IX. Chap. 41 of 10th book of *Les Oeuvres d'Ambroise Paré*, Paris, Gabriel Buon, 1598.

PARKER, H.L.: Trigeminal neuralgic pain associated with multiple sclerosis. *Brain, 51*:46-62, 1928.

PARKER, H.L.: Paroxysmal trigeminal pain with tumours of nervus acusticus. *J. Neurol. & Psychopath.*, *17*:236-261, 1937.

PASTORE, P. N. and MEREDITH, J.M.: Glossopharyngeal neuralgia. *Arch. Otolaryngol, 50*:789-794, 1949.

PATRICK, H.T.: The treatment of trifacial neuralgia by means of deep injections of alcohol. Report of sixteen cases. *J.A.M.A.*, *49*:1567-1574, 1907.

PATRICK, H.T.: The technic and results of deep injections of alcohol for trifacial neuralgia. *J.A.M.A.*, *58*:155-163, 1912.

PATRICK, H.T.: The symptomatology of trifacial neuralgia. *J.A.M.A.*, *62*:1519-1525, 1914.

PEARL, F.L.: *Muscle-splitting extraperitoneal lumbar ganglionectomy. Surg., Gynec. & Obst.*, 65:107-112, 1937.

PEARSON, A.A.: Role of gelatinous substance of spinal cord in conduction of pain. *Arch. Neurol. & Psychiat.*, 68:515-529, 1952.

PEET, M.M.: The control of intractable pain in lumbar region, pelvis and lower extremities, by section of the anterolateral columns of the spinal cord (chordotomy). *Arch. Surg.*, *13*:153-204, 1926

PEET, M.M.: Post-herpetic trigeminal neuralgia: Persistence of pain after section of sensory root of Casserian ganglion. *J.A.M.A.*, *92*:1503-1505, 1929.

PEET, M.M.: Glossopharyngeal neuralgia. *Ann. Surg.*, *101*:256-268, 1935.

PEET, M.M.: Discussion of paper by L. J. KARNOSH and R. F. SCHERB, Trophic lesions in the distribution of the trigeminal nerve. *J.A.M.A.*, *115*:2144-2148, 1940.

PEET, M.M. and ECHOLS, D.H.: Surgery of disorders of cranial nerves, Section Three, Chap. 14, in *Surgical Treatment of the Nervous System.* Edited by F. W. BANCROFT and C. PILCHER, Philadelphia, Lippincott, 1946, pp. 249-284.

PEET, M.M., KAHN, E.A. and ALLEN, S.: Bilateral cervical cordotomy for relief of pain in chronic infectious arthritis. *J.A.M.A.*, *100*.486-489, 1933.

PEET, M.M. and SCHNEIDER, R.C.: Trigeminal neuralgia; a review of 689 cases with a follow-up study of 65 per cent of the group. *J. Neurosurg*, *9*:367-377, 1952.

PENFIELD, W.: Operative treatment of migraine and observations on the mechanism of vascular pain. *Tr. Am. Acad. Ophthal & Otolaryngol.*, *37*:50-64, 1932.

PENFIELD, W.: A contribution to the mechanism of intracranial pain. *Research Publ. A. Nerv. & Ment Dis*, *23*:416-433, 1935

PENFIELD, W.: Discussion of paper by B. STOOKEY, The management of intractable pain by chordotomy. *Research Publ A. Nerv. & Ment. Dis.*, *23*:416-433, 1943.

PENFIELD, W. and BOLDREY, E.: Somatic motor and sensory representation in the cerebral cortex of man studied by electrical stimulation. *Brain, 60*:389-443, 1937.

PENFIELD, W and MCNAUGHTON, F.: Dural headache and innervation of the dura mater. *Arch. Neurol. & Psychiat.*, *44*:43-75, 1940.

PENFIELD, W. and WELCH, K: The supplementary motor area of the cerebral cortex: A clinical and experimental study. *Arch Neurol. & Psychiat.*, *66*:289-317, 1951.

PENMAN, J.: A simple radiological aid to Gasserian injection. *Lancet*, *257*:268-274, 1949.

PENMAN, J: The differential diagnosis and treatment of tic douloureux. *Postgrad. M. J.*, *26*.627-636, 1950.

PENMAN, J. and SMITH, M C.: Degeneration of the primary and secondary sensory neurones after trigeminal injection. *J. Neurol., Neurosurg. & Psychiat.*, *13*:36-46, 1950.

PETIT-DUTAILLIS, M · A propos des indications de la cordotomie (cordotomie au lieu d'élection et cordotomie cervicale haute). *Rev. neurol*, 68:347-352, 1937.

PETRÉN, K.: Ein Beitrag zur Frage vom Verlaufe der Bahnen der Hautsinne im Rückenmarke. *Skand. Arch. Physiol*, 13.9-98, 1902.

de PEYSTER, F.A., PAUL, O. and GILCHRIST, R.K.: Risk of urgent surgery in presence of myocardial infarction and angina pectoris. *Arch. Surg.*, 65.448-456, 1952.

PHILIPPIDES, D. Du traitement de la névralgie faciale par l'électrocoagulation. *Presse méd*, 55:423-424, 1947.

PICKERING, G.W and HESS, W.: Observations on the mechanism of headache produced by histamine *Clin. Sc.*, 1·77-100, 1933

PIERI, G.: Énervation ou ramisection? *Presse méd.*, 34.1141-1142, 1926.

PITKIN, G.P.: *Conduction anesthesia: Clinical studies*, edited by J. L. SOUTHWORTH and R. A. HINGSON, Philadelphia, Lippincott, 1946, 981 pp.

POCHIN, E.E Delay of pain perception in tabes dorsalis. *Clin. Sc.*, 3:191-196, 1938.

POLLOCK, L J. Overlap of so-called protopathic sensibility as seen in peripheral nerve lesions. *Arch. Neurol & Psychiat*, 2.667-700, 1919.

POLLOCK, L J. and POTTER, H.E.: Experimental studies of injection of the gasserian ganglion controlled by fluoroscopy. *J.A.M.A.*, 67·1357-1360, 1916.

POOL, J L : Posterior cordotomy for relief of phantom limb pain. *Ann. Surg*, 124 386-391, 1946.

POOL, J.L · Topectomy· A surgical procedure for the treatment of mental illnesses *Arch. Neurol. & Psychiat.*, 65:105-106, 1951.

POPOW, N.: Contribution à l'étude du syndrome de l'artère cérébelleuse postérieure et inférieure. *Rec neurol.*, 38:212-224, 1931.

POPPEN, J.L. Technic of prefrontal lobotomy. *J. Neurosurg*, 5:514-520, 1948.

PORTUGAL, J.R.. O tratamento cirurgico da trigeminalgia, neurotomia retrogasseriana por via temporal, intradural *Hospital, Rio de Janeiro*, 29.501-536, 1946.

PUDENZ, R.H. and SHELDEN, C.H.. Experiences with foraminal decompression in the surgical treatment of tic douloureux. Presented at meeting of American Academy of Neurological Surgery, New York, October 1, 1952.

PUECHBERTY, G.. L'énervation dans la coxarthrie. University of Toulouse thesis, 1947, 65 pp.

PUTNAM, T.J · Myelotomy of the commissure. A new method of treatment for pain in the upper extremities. *Arch Neurol. & Psychiat.*, 32:1189-1193, 1934.

PUTNAM, T J.. Treatment of unilateral paralysis agitans by section by the lateral pyramidal tract. *Arch. Neurol. & Psychiat*, 44.950-976, 1940.

PUTNAM, T.J. and HAMPTON, A O.: A technic of injection into the Gasserian ganglion under roentgenographic control *Arch Neurol. & Psychiat.*, 35.92-98, 1936.

PUTNAM, T J. and HERZ, E.. Results of spinal pyramidotomy in the treatment of the parkinsonian syndrome. *Arch. Neurol. & Psychiat.*, 63:357-366, 1950.

RAAF, J.: Discussion of paper by F. H. MAYFIELD and C. R. HUNTER on "Role of the upper cervical roots in the production of pain in the head and face," presented at meeting of American Academy of Neurological Surgery, Timberline, Oregon, Oct. 27, 1949

RACK, F.J. and ELKINS, C W.: Experience with vagotomy and sympathectomy in the treatment of chronic recurrent pancreatitis. *Arch. Surg.*, 61.937-943, 1950.

RAMON y CAJAL, S.: See CAJAL

RANEY, R B.· Etiologic factors in the production of atypical trigeminal neuralgia Presented at meeting of Harvey Cushing Society, Hot Springs, Va., Nov. 13, 1947.

RANEY, R.B., RANEY, A A. and HUNTER, C.R : Treatment of major trigeminal neuralgia through section of the trigeminospinal tract in the medulla. *Am. J Surg.*, 80:11-17, 1950.

RANSON, S.W.: Cutaneous sensory fibres and sensory conduction. *Arch. Neurol. & Psychiat.*, 12.1122-1144, 1931.

RANSON, S.W. and BILLINGSLEY, P.R.: The conduction of painful afferent impulses in the spinal nerves. *Am. J. Physiol*, 40.571-584, 1916

RANSON, S.W. and BILLINGSLEY, P.R.: The superior cervical ganglion and the cervical portion of the sympathetic trunk. *J. Comp. Neurol*, 29.313-358, 1918.

Ranson, S.W. and Clark, S.L.: *The Anatomy of the Nervous System: Its Development and Function.* 8th ed. Philadelphia, Saunders, 1947, 532 pp.

Rasmussen, A.T. and Peyton, W.T.: The location of the lateral spinothalamic tract in the brain stem of man. Surgery, 10:699-710, 1941.

Rasmussen, T. and Freedman, H.: Treatment of causalgia. An analysis of 100 cases. *J. Neurosurg.*, 3:165-173, 1946.

Rasmussen, T. and Penfield, W.: Further studies of the sensory and motor cerebral cortex of man. *Federation Proc.*, 6:452-460, 1947.

Ray, B.S.: The management of intractable pain by posterior rhizotomy. *Research Publ. A. Nerv. & Ment. Dis.*, 23:391-407, 1943.

Ray, B.S. and Console, A.D.: The relief of pain in chronic (calcareous) pancreatitis by sympathectomy. *Surg., Gynec. & Obstet.*, 89:1-8, 1949.

Ray, B.S. and Neill, C.L.: Abdominal visceral sensation in man. *Ann. Surg.*, *126*:709-724, 1947.

Ray, B.S. and Stewart, H.J.: Glossopharyngeal neuralgia: A cause of cardiac arrest. *Am. Heart J.*, *35*:458-462, 1948.

Ray, B.S. and Wolff, H.G.: Experimental studies on headache: Pain-sensitive structures of the head and their significance in headache. *Arch. Surg.*, *41*:813-856, 1940.

Ray, B.S. and Wolf, H.G.: Studies in pain: "Spread of Pain": Evidence on site of spread within the neuraxis of effects of painful stimulation. *Arch. Neurol. & Psychiat.*, *53*:257-261, 1945.

Reichert, F.L.: Glossopharyngeal neuralgia. *West. J. Surg.*, 39:347-353, 1931.

Reichert, F.L.: Three cases of glossopharyngeal neuralgia cured by intracranial section of the nerve. *Surg. Clin. North America*, *13*:193-204, 1933A.

Reichert, F.L.: Tympanic plexus neuralgia: True tic douloureux of the ear or so-called geniculate ganglion neuralgia: Cure effected by intracranial section of the glossopharyngeal nerve. *J.A.M.A.*, *100*:1744-1746, 1933B.

Reichert, F.L.: Neuralgias of the glossopharyngeal nerve, with particular reference to the sensory, gustatory and secretory functions of the nerve. *Arch. Neurol. & Psychiat.*, 32:1030-1037, 1934.

Reichert, F.L.: Treatment of the neuralgias of the head and face. *Proc. 2nd Congr. Pan-Pacific Surg. A.*, 1936, p. 183.

Reichert, F.L.: Communication, 1947, cited by O. Sugar and P. C. Bucy in "Postherpetic trigeminal neuralgia." *Arch. Neurol. & Psychiat.*, 65:131-145, 1951.

Reichert, F.L. and Poth, E.J.: Recent knowledge regarding the physiology of the glossopharyngeal nerve in man with an analysis of its sensory, motor, gustatory and secretory functions. *Bull. Johns Hopkins Hosp.*, 53:131-139, 1933A.

Reichert, F.L. and Poth, E.J.: Pathways for the secretory fibers of the salivary glands in man. *Proc. Soc. Exper. Biol., New York*, *30*:973-977, 1933B.

von Reis, G.: Pain in the distribution area of the fourth lumbar root; study of pain interpreted as referred pain and as caused by direct irritation of nerve-root. *Acta psychiat., Kbh.*, 1945, Suppl. 36, 135 p.

Reitman, F.: Orbital cortex syndrome following leucotomy. *Am. J. Psychiat.*, *103*:238-241, 1946.

Revilla, A.C.: Tic douloureux and its relationship to tumors of the posterior fossa. Analysis of 24 cases. *J. Neurosurg.* 4:233-239, 1947.

Rhinehart, D.A.: The nervus facialis of the albino mouse. *J. Comp. Neurol.*, 30:81-125, 1919.

Richins, C.A.: The innervation of the pancreas. *J. Comp. Neurol.*, *83*:223-236, 1945.

Riddoch, G.: The clinical features of central pain. *Lancet*, *234*:1150-1156 and 1205-1209, 1938.

Riddoch, G.: Phantom limbs and body shape. *Brain*, *64*:197-222, 1941.

Riley, H.A.: *An Atlas of the Basal Ganglia, Brain Stem and Spinal Cord.* Baltimore, Williams and Wilkins, 1943, 708 pp.

Riley, H.A., German, W.J., Wortis, H., Herbert, C., Zahn, D. and Eichna, L.: Glossopharyngeal neuralgia initiating or associated with cardiac arrest. *Tr. Am. Neurol. A.*, *68*:28-29, 1942.

Rivers, W H.R. and Head, H.: A human experiment in nerve division. *Brain, 31*:323-450, 1908.
Robson, J.T. and Bonica, J.: The vagus nerve in surgical consideration of glossopharyngeal neuralgia. *J. Neurosurg., 7*:482-491, 1950.
Rosen, S : Tic douloureux of the chorda tympani. *Arch. Neurol. & Psychiat, 69*:375-378, 1953.
Rosenfeld, M.H.. Results obtained by treating severe cardiac disease in euthyroid patients with radioiodine. *Ann. West. Med. Surg, 5*.923-925, 1951.
Ross, J . On the segmental distribution of sensory disorders. *Brain, 10*:333-361, 1888.
Ross, J.P : Causalgia. *St. Barth. Hosp. Rep., 65*:103-118, 1932.
Roth, W.K · *Meralgia Paraesthetica.* Berlin, S. Karger, 1895.
Rothman, S.: Anterior cordotomy. *Arch. Neurol. & Psychiat., 50*:129-148, 1943.
Roulhac, G E. and Levy, I.: Glossopharyngeal neuralgia associated with cardiac arrest and convulsions. *Arch Neurol. & Psychiat., 63*:133-139, 1950.
Roussy, G : Deux nouveaux cas de lesions de la cauche optique suivis d'autopsie. *Rev. neurol., 17*:301-317, 1909.
Rowbotham, G.F : Treatment of pain in the face by intramedullary tractotomy. *Brit. M. J.,* 2 1073-1076, 1938.
Rowbotham, G F.: Observations on the effects of trigeminal denervation. *Brain, 62*.364-380, 1939.
Rowbotham, G.F.. The pain pathways in migraine. *Brit. M. J.,* 2.685-687, 1942.
Rowbotham, G.F . Migraine and the sympathetic nervous pathways. *Brit. M. J.,* 2.219-322, 1946.
Rowbotham, G.F:. The surgical treatment of migraine. *IVe Congr. neurol. int., 1*:147-152, 1949.
Rowe, S.N.: Mental changes following the removal of the right cerebral hemispheres for brain tumor *Am J Psychiat., 94*.604-612, 1937.
Rowe, S.N.: Discussion of paper by R. H. Pudenz and C. H. Shelden on "Experiences with foraminal decompression in the surgical treatment of tic douloureux," presented at meeting of American Academy of Neurological Surgery, New York, Oct. 1, 1952.
Ruch, T.C.: Visceral sensation and referred pain. Chap. 19 in *A Textbook of Physiology.* 16th ed., edited by J. F. Fulton, Philadelphia, Saunders, 1949, pp. 360-374.
Russel, C.K The syndrome of the brachium conjunctivum and the tractus spinothalamicus. *Arch Neurol. & Psychiat., 25*:1003-1010, 1931.
Russel, C.[K] and Stavraky, G.W : The syndrome of the posterior inferior cerebellar artery. *Canad M A. J., 30*:358-364, 1934
Russell, W.R · Painful amputation stumps and phantom limbs Treatment by repeated percussion to the stump neuromata *Brit. M J , 1*:1024-1026, 1949.
Russell, W.R and Spalding, J M.K · Treatment of painful amputation stumps *Brit M. J.,* 2.68-73, 1950.
Sachs, E.: The diagnosis and treatment of trigeminal neuralgia. *Tri-state M. J ,* 7.1416-1420, 1935.
Sarnoff, S.J and Arrowood, J.G.: Differential spinal block: A preliminary report *Surgery, 20*:150-159; 1946
Sarnoff, S.J., Arrowood, J.G. and Chapman, W.P : Differential spinal block. IV. The investigation of intestinal dyskinesia, colonic atony, and visceral afferent fibers *Surg , Gynec. & Obst , 86*.571-581, 1948.
Sasaki, K.: Über die Wirkung der Chordotomie auf Spontangangren. *Arch. klin Chir., 192* 448-461, 1938.
Scarff, J E.: Unilateral prefrontal lobotomy with relief of ipsilateral, contralateral, and bilateral pain. A preliminary report. *J. Neurosurg , 5* 288-293, 1948
Scarff, J.E.: Unilateral prefrontal lobotomy for the relief of intractable pain. Report of 58 cases with special consideration of failures *J. Neurosurg ,* 7.330-336, 1950.
Schafer, E.A · Note on the occurrence of ganglion cells in the anterior roots of the cat's spinal nerves. *Proc. Roy. Soc. London, 31*.348, 1880.

SCHIFF, J.M: *Muskel und Nervenphysiologie.* Vol. 1 of *Lehrbuch der Physiologie des Menschen.* Lahr, M. Schauenburg, 1858, 424 pp.
SCHMIDT, E.R. and SZEJEWSKI, H.A.: Atypical neuralgia of the face. *Arch. Surg., 56:*785-793, 1948.
SCHÜLLER, A.: Über operative Durchtrennung der Rückenmarksstränge (Chordotomie). *Wien. med. Wchnschr., 60:*2292-2296, 1910.
SCHUMACHER, G.A.: The influence of inflammation on the pain threshold of the skin in man. *Research Publ. A. Nerv. & Ment. Dis., 23:*166-172, 1943.
SCHWARTZ, H.G.: Neurosurgical relief of intractable pain. *Surg. Clin. North America, 30:*1379-1389, 1950.
SCHWARTZ, H.G. and O'LEARY, J.L.. Section of the spinothalamic tract in the medulla with observations on the pathway for pain. *Surgery, 9:*183-193, 1941.
SCHWARTZ, H.G. and O'LEARY, J.L.: Section of the spinothalamic tract at the level of the inferior olive. *Arch. Neurol. & Psychiat., 47:*293-304, 1942.
SCHWARTZ, H.G. and WEDDELL, G.: Observations on the pathways transmitting the sensation of taste. *Brain, 61:*99-115, 1938
SCHWARZ, E.: Über den anatomischen und klinischen Befund bei Verschluss der Arteria cerebelli posterior inferior. *Mschr. Psychiat. Neurol., 32:*132-159, 1912.
SCOTT, M and WYCIS, H.T: Survey of the value of neurosurgical treatment for the relief of intractable pain. *Am. J. Surg., 77:*718-736, 1949.
SCOTT, W.J.M. and SCHROEDER, C.F.: Denervation of the bladder for relief of intractable pain. *Ann Surg., 108:*730-740, 1938.
SCOVILLE, W B.: Discussion of paper by R. B. RANEY on "Etiologic factors in the production of atypical trigeminal neuralgia," presented at meeting of Harvey Cushing Society, Hot Springs, Va., Nov. 13, 1947.
SCOVILLE, W.B.: Selective cortical undercutting as a means of modifying and studying frontal lobe function in man. Preliminary report of forty-three operative cases. *J. Neurosurg., 6:*65-73, 1949.
SCRIMGER, F.A C.: On the possibility of relieving abdominal pain by section of the sympathetic rami communicantes. *Canad. M.A.J., 21:*184-189, 1929.
SERRA, A. and NERI, U.: Die elektro-chirurgische Unterbrechung der Zentralbahnen des V Paares am lateralen ventralen Rand des Pons Varoli als erster Behandlungsversuch von hartnäckigen Neuralgien des Trigeminus durch Tumoren der Schädelbasis. *Zentralbl. Chir., 63:*2248-2250, 1936.
SHAFIROFF, B.G P. and HINTON, J.W.: Surgical anatomy of the choledochal nerves. *Arch. Surg., 60:*944-952, 1950.
SHAW, R B . Sympathetic system and pain phenomena *Arch. Surg., 27:*1072-1080, 1933.
SHEEHAN, D.: The cell station of the Vater-Pacinian corpuscle in retroperitoneal tissue. An afferent peripheral pathway in the sympathetic *Brain, 55:*493-498, 1932.
SHEEHAN, D.: The afferent nerve supply of the mesentery and its significance in the causation of abdominal pain. *J. Anat, 67:*233-249, 1933.
SHERMAN, J.C. and ARIEFF, A.J.: Dissociation between pain and temperature in spinal cord lesions. *J Nerv. & Ment. Dis., 108:*285-292, 1948.
SHERRINGTON, C.S : On the anatomical constitution of nerves of skeletal muscles; with remarks on recurrent fibres in the ventral spinal nerve root. *J. Physiol, 17:*211-258, 1894A.
SHERRINGTON, C S . Experiment in examination of the peripheral distribution of the fibres of the posterior roots of some spinal nerves *Philos. Trans., London, 184(B):*641-763, 1894B.
SHERRINGTON, C S.: *Man on his Nature.* (Gifford Lectures) London, Cambridge University Press, 1940, 413 pp.
SHUMACKER, H B.,JR : Causalgia. III. A general discussion. *Surgery, 24:*485-504, 1948A.
SHUMACKER, H.B ,JR.: Surgery in peripheral vascular disease. *Surg. Clin. North America, 28:*294-303, 1948B.
SHUMACKER, H.B ,JR.: Sympathetic denervation of the extremities, operative technique, morbidity, and mortality. *Surgery, 24:*304-325, 1948C.

RIVERS, W.H.R and HEAD, H.: A human experiment in nerve division. *Brain, 31*.323-450, 1908.
ROBSON, J.T. and BONICA, J.: The vagus nerve in surgical consideration of glossopharyngeal neuralgia. *J. Neurosurg., 7*:482-491, 1950.
ROSEN, S.: Tic douloureux of the chorda tympani. *Arch. Neurol. & Psychiat., 69*:375-378, 1953.
ROSENFELD, M.H.: Results obtained by treating severe cardiac disease in euthyroid patients with radioiodine *Ann. West. Med. Surg., 5*:923-925, 1951.
ROSS, J : On the segmental distribution of sensory disorders. *Brain, 10* 333-361, 1888.
ROSS, J.P.. Causalgia. *St. Barth Hosp. Rep., 65*:103-118, 1932.
ROTH, W K.: *Meralgia Paraesthetica*. Berlin, S. Karger, 1895.
ROTHMAN, S.. Anterior cordotomy. *Arch. Neurol. & Psychiat., 50*:129-148, 1943.
ROULHAC, G.E. and LEVY, I.: Glossopharyngeal neuralgia associated with cardiac arrest and convulsions. *Arch. Neurol & Psychiat., 63*:133-139, 1950.
ROUSSY, G.· Deux nouveaux cas de lesions de la cauche optique suivis d'autopsie. *Rev. neurol, 17* 301-317, 1909.
ROWBOTHAM, G F.. Treatment of pain in the face by intramedullary tractotomy. *Brit. M. J.*, 2.1073-1076, 1938.
ROWBOTHAM, G.F . Observations on the effects of trigeminal denervation. *Brain*, 62.364-380, 1939.
ROWBOTHAM, G.F.: The pain pathways in migraine. *Brit. M. J.*, 2.685-687, 1942.
ROWBOTHAM, G F.: Migraine and the sympathetic nervous pathways. *Brit. M. J*, 2.219-322, 1946.
ROWBOTHAM, G.F:. The surgical treatment of migraine. *IVe Congr. neurol. int*, *1*.147-152, 1949
ROWE, S.N : Mental changes following the removal of the right cerebral hemispheres for brain tumor *Am. J Psychiat*, *94*.604-612, 1937.
ROWE, S.N.· Discussion of paper by R. H PUDENZ and C. H. SHELDEN on "Experiences with foraminal decompression in the surgical treatment of tic douloureux," presented at meeting of American Academy of Neurological Surgery, New York, Oct. 1, 1952.
RUCH, T.C : Visceral sensation and referred pain. Chap. 19 in *A Textbook of Physiology*, 16th ed., edited by J. F. FULTON, Philadelphia, Saunders, 1949, pp 360-374.
RUSSEL, C K . The syndrome of the brachium conjunctivum and the tractus spinothalamicus. *Arch Neurol & Psychiat*, *25* 1003-1010, 1931
RUSSEL, C.[K.] and STAVRAKY, G.W.: The syndrome of the posterior inferior cerebellar artery. *Canad. M. A J, 30*.358-364, 1934.
RUSSELL, W R · Painful amputation stumps and phantom limbs. Treatment by repeated percussion to the stump neuromata. *Brit. M. J*, *1*:1024-1026, 1949
RUSSELL, W.R and SPALDING, J.M.K : Treatment of painful amputation stumps *Brit M. J.*, 2:68-73, 1950.
SACHS, E.. The diagnosis and treatment of trigeminal neuralgia. *Tri-state M. J.*, 7.1416-1420, 1935.
SARNOFF, S J and ARROWOOD, J G. Differential spinal block. A preliminary report *Surgery, 20*.150-159, 1946.
SARNOFF, S J., ARROWOOD, J.G. and CHAPMAN, W.P.: Differential spinal block. IV. The investigation of intestinal dyskinesia, colonic atony, and visceral afferent fibers *Surg, Gynec. & Obst., 86*.571-581, 1948.
SASAKI, K.: Über die Wirkung der Chordotomie auf Spontangangren. *Arch klin. Chir*, *192* 448-461, 1938.
SCARFF, J.E.: Unilateral prefrontal lobotomy with relief of ipsilateral, contralateral, and bilateral pain. A preliminary report. *J. Neurosurg.*, 5 288-293, 1948.
SCARFF, J E.: Unilateral prefrontal lobotomy for the relief of intractable pain Report of 58 cases with special consideration of failures. *J. Neurosurg., 7*:330-336, 1950.
SCHAFER, E.A . Note on the occurrence of ganglion cells in the anterior roots of the cat's spinal nerves. *Proc. Roy. Soc. London, 31*:348, 1880.

SPIEGEL, E.A. and WYCIS, H.T.: Mesencephalotomy in treatment of "intractable" facial pain. *Arch. Neurol. & Psychiat.*, 69:1-13, 1953A.

SPIEGEL, E.A. and WYCIS, H.[T.]: Use of the stereo-encephalotome in atypical face pain. Presented at meeting of New York Academy of Medicine, Feb. 17, 1953 (*B*).

SPILLER, W.G.: The occasional clinical resemblance between caries of the vertebrae and lumbothoracic syringomyelia, and the location within the spinal cord of the fibres for the sensations of pain and temperature. *Univ. Pennsylvania Med. Bull.*, 18:147-154, 1905.

SPILLER, W.G.: Central pain in syringomyelia and dysesthesia and over-reaction to sensory stimuli in lesions below the optic thalamus. *Arch. Neurol. & Psychiat.*, 10:491-499, 1923.

SPILLER, W.G. and FRAZIER, C.H.: The division of the sensory root of the trigeminus for the relief of tic douloureux; an experimental, pathological and clinical study, with a preliminary report of one surgically successful case. *Philadelphia Med. J.*, 8:1039-1049, 1901.

SPILLER, W.G. and MARTIN, E.: The treatment of persistent pain of organic origin in the lower part of the body by division of the anterolateral column of the spinal cord. *J.A.M.A.*, 58:1489-1490, 1912.

SPURLING, R.G.: The use of tantalum wire and foil in the repair of peripheral nerves. *Surg. Clin. North America*, 23:1491-1504, 1943.

SPURLING, R.G.: Discussion of paper by R. B. RANEY on "Etiological factors in the production of atypical trigeminal neuralgia," presented at *meeting of Harvey Cushing Society*, Hot Springs, Va., Nov. 13, 1947.

SPURLING, R.G. and GRANTHAM, E.G.: Glossopharyngeal neuralgia. *South. M. J.*, 35:509-513, 1942.

STARZL, T.E. and MAGOUN, H.W.: Organization of the diffuse thalamic projection system. *J. Neurophysiol.*, 14:133-146, 1951.

STARZL, T.E., TAYLOR, C.W. and MAGOUN, H.W.: Ascending conduction in reticular activating system with special reference to the diencephalon. *J. Neurophysiol.*, 14:461-477, 1951. Collateral afferent excitation of reticular formation of brain stem. *J. Neurophysiol.*, 14:479-496, 1951.

STARZL, T.E. and WHITLOCK, D.G.: Diffuse thalamic projection system in monkey. *J. Neurophysiol.*, 15:449-468, 1952.

STEBBING, G.F.: Chordotomy: Section of the anterolateral tracts for the relief of pain, with notes of seventeen cases. *Lancet*, 216:654-656, 1929.

STEINBROCKER, O.: The shoulder-hand syndrome: Associated painful homolateral disability of the shoulder and hand with swelling and atrophy of the hand. *Am. J. Med.*, 3:402-407, 1947.

STEINBROCKER, O., SPITZER, N. and FRIEDMAN, H.H.: The shoulder-hand syndrome in reflex dystrophy of the upper extremity. *Ann. Int. Med.*, 29:22-52, 1948.

STÖHR, P., JR.: Das periphere Nervensystem, Band IV, Teil I, of *Handbuch der mikroskopischen Anatomie des Menschen*, edited by W. V. MOLLENDORFF, Berlin, Springer, 1928, pp 202-423.

STONE, E.: Renal sympathectomy: Report of two cases, including one fatality. *New England J. Med.*, 210:1257-1262, 1934.

STONE, T.T.: Phantom limb pain and central pain, relief by ablation of portion of posterior central cerebral convolution. *Arch. Neurol. & Psychiat.*, 63:739-748, 1950.

STOOKEY, B.: Glossopharyngeal neuralgia — surgical treatment with remarks on the distribution of the glossopharyngeal nerve. *Arch. Neurol. & Psychiat.*, 20:702-719, 1928A.

STOOKEY, B.: Meralgia paraesthetica: Etiology and surgical treatment. *J.A.M.A.*, 90:1705-1707, 1928B.

STOOKEY, B.: Further light on the transmission of pain and temperature within the spinal cord: Human cordotomy to abolish pain sense without destroying the temperature sense. *J. Nerv. & Ment. Dis.*, 69:552-557, 1929.

STOOKEY, B.: The management of intractable pain by chordotomy. *Research Publ. A. Nerv. & Ment. Dis.*, 23:416-433, 1943.

SHUMACKER, H.B., JR. and ABRAMSON, D.I.: Posttraumatic vasomotor disorders with particular reference to late manifestations and treatment. *Surg., Gynec. & Obst.*, 88:417-431, 1949.

SICARD, J.A., HAGUENAU, J. and MAYER, C.: Radicotomie postérieure "élargie" pour causalgie du membre supérieur—Guérison—Etude des troubles sensitivo-moteurs postopératoires. *Rev. neurol.*, 1:1224-1228, 1926.

SICARD, J.A., HAGUENAU, J. and WALLICH, R.: Cordotomie latérale antérieure dans une algie paroxystique du moignon. Isothermopnosie. *Bull. Soc. méd. Hôp. Paris*, 51:1219-1221, 1927.

SICARD, J.A. and ROBINEAU: Communications et présentations: I. Algie vélopharyngée essentielle. Traitement chirurgical. *Rev. neurol.*, 34:256-257, 1920.

SICARD, J.A. and ROBINEAU: Cordotomie latérale antérieure pour les algies incurables. *Rev. neurol.*, 1:21-28, 1925.

SINCLAIR, D.C., FEINDEL, W.H., WEDDELL, G. and FALCONER, M.A.: The intervertebral ligaments as a source of segmental pain. *J. Bone & Joint Surg.*, 30-B:515-521, 1948.

SINCLAIR, D.C., WEDDELL, G. and FEINDEL, W.H.: Referred pain and associated phenomena. *Brain*, 71:184-211, 1948.

SJOQVIST, O.: Studies on pain conduction in the trigeminal nerve. A contribution to the surgical treatment of facial pain. *Acta psychiat., Kbh.*, 1938A, *Suppl. 17*, 139 pp.

SJOQVIST, O.: Eine neue Operationsmethode bei Trigeminus-neuralgie: Durchschneidung des Tractus spinalis trigemini. *Zentralbl. Neurochir.*, 2:274-281, 1938B.

SJOQVIST, O.: Ten years' experience with trigeminal tractotomy. *Brasil Méd. Cirúrg.*, 10:259-274, 1948.

SJOQVIST, O.: Surgical section of pain tracts and pathways in the spinal cord and brain stem. *IVe Congr. neurol.*, 1:119-132, 1949.

SJOQVIST, O. and WEINSTEIN, E.A.: The effect of section of the medial lemniscus on proprioceptive functions in chimpanzees and monkeys. *J. Neurophysiol.*, 5:69-74, 1942.

SLAUGHTER, R.F.: Relief of causalgic-like pain in isolated extremity by sympathectomy, case report. *J. Med. A. Georgia*, 27:253-256, 1938.

SLESSOR, A.J.: Causalgia: A review of 22 cases. *Edinburgh M. J.*, 55:563-571, 1948.

SLESSOR, A.J. and LEARMONTH, J.: Pain in peripheral vascular disease. *Practitioner*, 163:445-454, 1949.

SLUDER, G.: Hyperplastic sphenoiditis and its clinical relations to the second, third, fourth, fifth, sixth and vidian nerves and nasal ganglion. *Tr. Am. Laryng. A.*, 37:215-242, 1915.

SLUDER, G.: *Nasal Neurology, Headaches and Eye Disorders.* St. Louis, Mosby, 1927, 428 pp.

SMITH, L.A., MOERSCH, H.J. and LOVE, J.G.: Superior laryngeal neuralgia. *Proc. Staff Meet., Mayo Clin.*, 16:164-167, 1941.

SMITHWICK, R.H.: The problem of producing complete and lasting sympathetic denervation of the upper extremity by preganglionic section. *Ann. Surg.*, 112:1085-1100, 1940.

SMITHWICK, R.H. and WHITE, J.C.: Elimination of pain in obliterative vascular disease of the lower extremity: A technique for alcohol injection of the sensory nerves of the lower leg. *Surg., Gynec. & Obst.*, 51:394-403, 1930.

SMITHWICK, R.H. and WHITE, J.C.: Peripheral nerve block in obliterative vascular disease of the lower extremity: Further experience with alcohol injection or crushing of sensory nerves of lower leg. *Surg., Gynec. & Obst.*, 60:1106-1114, 1935.

SMYTH, G.E.: The systemization and central connections of the spinal tract and nucleus of the trigeminal nerve, clinical and pathological study. *Brain*, 62:41-87, 1939.

de SOUSA PEREIRA, A.: Blocking of the middle cervical and stellate ganglions with descending infiltration anesthesia. Technic, accidents and therapeutic indications. *Arch. Surg.*, 50:152-165, 1945.

de SOUSA PEREIRA, A.: Abdominopelvic sympathectomy for relief of pain of cancer of the cervix. *Arch. Surg.*, 52:113-134, 1946.

SPEIGEL, I.J. and MILOWSKY, J.L.: Causalgia: A preliminary report of nine cases successfully treated by surgical and chemical interruption of the sympathetic pathways. *J.A.M.A.*, 127:9-15, 1945.

THEOBALD(?)...

TIMOFEJEW, D.A.: Über die Nervendigungen im Bauchfell und im Diaphragma der Säugetiere. *Arch. mikr. Anat.*, 59:629-646, 1902.

TÖNNIS, W. and KRENKEL, H.: Die Bedeutung einer sorgfältigen Differentialdiagnose für die chirurgische Behandlung der Trigeminus-neuralgie. *Deutsche med. Wchnschr.*, 76:1202, 1951.

TOWER, S.S.: Pain: Definition and properties of the unit for sensory reception. *Research Publ. A. Nerv. & Ment. Dis.*, 23:16-43, 1943.

TRIMBLE, I.R. and MORRISON, S.: Treatment of intractable pain of visceral origin. *J.A.M.A.*, *148*:1181-1188, 1952.

TROTTER, W.: The insulation of the nervous system. *Brit. M. J.*, 2:103-107, 1926.

TROTTER, W. and DAVIES, H.M.: Experimental studies in the innervation of the skin. *J. Physiol.*, 38:134-246, 1909.

TROTTER, W. and DAVIES, H.M.: The peculiarities of sensibility found in cutaneous areas supplied by regenerating nerves. *J. Psychol. & Neurol., Lpzig., Ergänzungshft.*, 20.102-150, 1913.

TURLEN, L.L. and GITT, J.J.: Cauda equina syndrome following subarachnoid alcohol injection. Report of two cases. *J.A.M.A.*, *106*:1535-1537, 1936.

TURNBULL, F: Cordotomy for thalamic pain. A case report. *Yale J. Biol. Med.*, *11*:411-414, 1939.

ULMER, J.L. and MAYFIELD, F.H.: Causalgia: A study of 75 cases. *Surg., Gynec. & Obstet.*, *83*:789-796, 1946

VAIL, H.H. Vidian neuralgia from disease of the sphenoidal sinus. Report of a case. *Arch. Surg.*, *18*:1247-1255, 1929.

VAIL, H.H.: Vidian neuralgia. *Ann Otol. Rhinol. & Laryngol*, *11*.837-856, 1932.

VAIL, H.H.: Vidian neuralgia: With special reference to the eye and orbital pain in suppuration of the petrous apex. *Arch. Otolaryng.*, *17*:212-221, 1933.

VAIL, H H.: Pathways of reflex pain in vidian neuralgia. *Arch. Otolaryng.*, *21*:277-284, 1935.

VAN VALKENBURG, C.T.: Zur Kenntnis der Radix spinalis nervi trigemini. *Mschr. Psychiat. Neurol*, 29.407-437, 1911.

VALLÉRY-RADOT, P. and BLAMOUTIER, P.: Syndrome de vasodilatation hémicéphalique d'origine sympathique. *Bull. Soc. méd. Hôp Paris*, *49*:1488-1493, 1925.

VAN BOGAERT, L. and VERBRUGGE, J.: The pathogenesis and the surgical treatment of gastric crisis of tabes Neuroramisectomy. *Surg., Gynec. & Obst.*, *47*:543-553, 1928.

VAN NOUHUYS, F: The anatomy of the gasserian ganglion. *Arch. Surg.*, 24.451-457, 1932.

DE VET, A C.: Post-herpetic neuralgia Paper presented before neurosurgical group at Harvard Club, Boston, April 12, 1952.

VIANNAY, C: Du traitement des cystites douloureuses arrivées au stade de "cystalgie" par les interventions sur le sympathique pelvien et, en particulier, par la résection du nerf présacré. *Arch. franco-belges Chir.*, *30*:229-236, 1927.

VORIS, H.C.. Ipsilateral sensory loss following chordotomy: Report of a case. *Arch. Neurol. & Psychiat*, *65* 95-96, 1951.

VORIS, H C. and BAKODY, J.T: Traumatic glossopharyngeal neuralgia. *Arch. Neurol. & Psychiat*, *54* 160, 1945

WALKER, A.E: *The Primate Thalamus.* Chicago, University of Chicago Press, 1938, 321 pp

WALKER, A E Anatomy, physiology, and surgical considerations of the spinal tract of the trigeminal nerve *J Neurophysiol.*, 2.234-248, 1939.

WALKER, A E: The spinothalamic tract in man *Arch Neurol. & Psychiat.*, *43*:284-298, 1940.

WALKER, A E. Relief of pain by mesencephalic tractotomy *Arch. Neurol. & Psychiat.*, *48*.865-883, 1942A

WALKER, A E.: Mesencephalic tractotomy: A method for the relief of unilateral intractable pain. *Arch Surg*, *44*.953-962, 1942B.

STRUGHOLD, H.: Über die Dichte und Schwellen der Schmerzpunkte der Epidermis in den verschiedenen Korperregionen. *Z. Biologie, 80*.367-380, 1924.

STURGE, W.A.: The phenomena of angina pectoris, and their bearing upon the theory of counter-irritation. *Brain, 5*:492-510, 1883.

SUDECK, P.: Ueber die akute entzundliche Knochenatrophie. *Arch. klin. Chir.*, 62.147-156, 1900.

SUGAR, O. and BUCY, P.C. Postherpetic trigeminal neuralgia. *Arch. Neurol. & Psychiat*, 65.131-145, 1951.

SUH, T H. and ALEXANDER, L.: Vascular system of the human spinal cord. *Arch. Neurol. & Psychiat*, *41*.659-677, 1939.

SUTTON, D.C. and LUETH, H.C.: Pain *Arch. Int. Med.*, *45*:827-867, 1930.

SWANK, R L and DAVENPORT, H.A.: Marchi's staining method: II. Fixation stain technique. *Stain Technology, 9*:129, 1934.

SWEET, W.H.: Extensive bulbar trigeminal tractotomy: Report of cases. Presented at meeting of Boston Society of Psychiatry and Neurology, Dec. 20, 1945.

SWEET, W.H.: Relief of pain by operations on the central nervous system. *Surg. Clin. North America, 27*:1254-1262, 1947.

SWEET, W.H : Bulbar trigeminal tractotomy: A new operative technique and results. Presented at meeting of Harvey Cushing Society, San Francisco, Aug. 19, 1948.

SWEET, W H.: Trigeminal injection with radiographic control. Technic and results. *J.A M.A*, *142*.392-396, 1950.

SWEET, W H., WHITE, J C., SELVERSTONE, B and NILGES, R.: Sensory responses from anterior roots and from surface and interior of spinal cord in man. *Tr. Am. Neurol. A.*, 165-169, 1950.

SWETLOW, G.I : Alcohol injections into nerve tissues for the relief of pain. *Am. J. Med* Sc., *171* 397-407, 1926A.

SWETLOW, G.I.: Paravertebral alcohol block in cardiac pain. *Am. Heart J*, *1*:393-412, 1926B.

SZABO, E.: Innervation of the kidney and its practical significance. *Acta Urol., 2*:31-39, 1948.

SZASZ, T.S.: Psychiatric aspects of vagotomy. IV. Phantom ulcer pain. *Arch. Neurol. & Psychiat., 62* 728-733, 1949.

SZENTAGOTHAI, J and KISS, T : Projection of dermatomes on the substantia gelatinosa. *Arch. Neurol. & Psychiat., 62*:734-744, 1949.

TAARNHØJ, P . Decompression of the trigeminal root and the posterior part of the ganglion as treatment in trigeminal neuralgia. *J. Neurosurg.*, 9.288-290, 1952

TAARNHØJ, P : Communication at meeting of the Society of Neurological Surgeons, New Orleans. La., April, 1953.

DE TAKATS, G.: Causalgic states in peace and war. *J.A.M.A., 128* 699-704, 1945.

DE TAKATS, G. and WALTER, L.E.: The treatment of pancreatic pain by splanchnic nerve section. *Surg, Gynec. & Obst*, *85* 742-746, 1947.

DE TAKATS, G., WALTER, L.E. and LASNER, J.: Splanchnic nerve section for pancreatic pain: Second report *Ann. Surg*, *131*:44-57, 1950

TALAIRACH, J., HÉCAEN, H., DAVID, M , MONNIER, M. and DE AJURIAGUERRA, J Recherches sur la coagulation thérapeutique des structures sous-corticales chez l'homme *Rev. Neurol*, *81* 4-24, 1949.

TARLOV, I.M.: Sensory and motor roots of the glossopharyngeal nerve and the vagus-spinal accessory complex. *Arch. Neurol. & Psychiat*, *44*:1018-1021, 1940.

TATLOW, W.F.T.: Herpes zoster ophthalamicus and post-herpetic neuralgia. *J. Neurol, Neurosurg. & Psychiat.*, 15:45-49, 1952

TAVERNIER, L. and GODINOT, C : *Traitement chirurgical de l'arthrite sèche de la hanche* Paris, Masson, 1945, 356 pp.

THEOBALD, G.W.: The rôle of the cerebral cortex in the apperception of pain. *Lancet*, 257.41-47 and 94-96, 1949.

THOMPSON, R H.: Occlusion of the posterior inferior cerebellar artery A clinical study of four cases. *Arch. Neurol. & Psychiat*, 22.530-546, 1929.

Weisenburg, T.H. and Stack, S.S.: Central pain from lesions of the pons. *Arch. Neurol. & Psychiat.*, *10*:500-511, 1923.

Weiss, S.: Therapeutic indications and the dangers of the intravenous administration of sodium-phenylethyl barbiturate (sodium luminal) and other barbituric acid derivatives. *Am. J. Med. Sc.*, *N.S 178*:390-405, 1929.

Weiss, S. and Davis, D.: The significance of the afferent impulses from the skin in the mechanism of visceral pain. Skin infiltration as a useful therapeutic measure. *Am. J. Med. Sc.*, *176*:517-536, 1928

Wernøe, T.B.: Viscero-cutane Reflexe. *Pflüg. Arch. ges. Physiol.*, *210*:1-34, 1925.

Wertheimer, P. and Mansuy, L.: Quelques tentatives neurochirurgicales centrales dans le traitement des douleurs irréductibles. *Rev. neurol.*, *81*:401-408, 1949A.

Wertheimer, P., and Mansuy, L.: Réflexions sur la topectomie préfrontale. *Rev. neurol.*, *81*:866-871, 1949*B*.

Wertheimer, P. and Sautot, J.: Les résultats de la myélotomie commissurale postérieure (à propos de 69 observations). *Le Concours Médical, Paris*, *71*:113-114, 1949.

Wetherell, F.S.: Relief of pelvic pain by sympathetic neurectomy. Report of seven cases in which the superior hypogastric plexus (presacral nerve) was resected. *J.A.M.A.*, *101*:1295-1299, 1933.

Wharton, L.R.: The innervation of the ureter, with respect to denervation. *J. Urol.*, *28*:639-673, 1932.

Whipple, A.O.: Radical surgery for certain cases of pancreatic fibrosis associated with calcareous deposits. *Ann. Surg.*, *124*:991-1008, 1946.

White, J.C. (the elder): Meralgia paresthetica. *J. Cutan. Dis.*, *24*:160-163, 1906

White, J.C.: Painful aneurysms of the aortic arch: Relief by paravertebral injections of procaine and alcohol. *J.A.M.A.*, *99*:10-13, 1932.

White, J.C.: A new modification of subarachnoid alcohol injection for the bilateral blocking of the lower sacral nerves in intractable pain of the pelvic viscera. *Surgery*, *4*:722-727, 1938.

White, J.C. Technique of paravertebral alcohol injection: Methods and safeguards in its use in the treatment of angina pectoris. *Surg., Gynec. & Obst.*, *71*:334-343, 1940.

White, J.C.: Spinothalamic tractotomy in the medulla oblongata: An operation for the relief of intractable neuralgias of the occiput, neck and shoulder. *Arch. Surg.*, *43*:113-127, 1941.

White, J.C.: Sensory innervation of the viscera: Studies on visceral afferent neurones in man based on neurosurgical procedures for the relief of intractable pain. *Research Publ. A. Nerv. & Ment. Dis.*, *23*:373-390, 1943.

White, J.C.: Pain following injuries of peripheral nerves. *U. S. Nav. Med. Bull.*, *45*:845-858, 1945.

White, J.C.: Surgery of sympathetic nervous system. Section Six, Chap. 19, in *Surgical Treatment of the Nervous System*, edited by F. W. Bancroft and C. Pilcher, Philadelphia, Lippincott, 1946A, pp. 457-504

White, J.C.: Painful injuries of nerves and their surgical treatment. *Am. J. Surg.*, *72*:468-488, 1946*B*.

White, J.C.: Procaine block of the sympathetic nerves in the study of intractable pain and circulatory disorders. *Surg. Clin. North America*, *27*:1263-1280, 1947.

White, J.C.: Frontal leucotomy versus cordotomy for relief of pain. *Surg., Gynec. & Obst.*, *92*:469-480, 1951

White, J.C. and Bland, E.F.: The surgical relief of severe angina pectoris: Methods employed and end results in 83 patients. *Medicine*, *27*:1-42, 1948.

White, J.C., Garrey, W.E. and Atkins, J.A.: Cardiac innervation. Experimental and clinical studies. *Arch. Surg.*, *26*:765-786, 1933

White, J.C. and Gentry, R.W.: Radiographic control for paravertebral injection of alcohol in angina pectoris. *J. Neurosurg.*, *1*:40-44, 1944.

White, J.C. and Hamlin, H.: New uses of tantalum in nerve suture, control of neuroma formation, and prevention of regeneration after thoracic sympathectomy: Illustration of technical procedures. *J. Neurosurg.*, *2*:402-413, 1945

Walker, A E.: Somatotopic localization of spinothalamic and secondary trigeminal tracts in mesencephalon. *Arch. Neurol. & Psychiat.*, *48*:881-889, 1942C.

Walker, A E.: Central representation of pain. *Research Publ. A. Nerv. Ment. Dis*, *23*.63-85, 1943.

Walker, A.E : The neurosurgical treatment of intractable pain. *Lancet*, *70*.279-282, 1950.

Walker, A.E.: Section of the sensory root of the trigeminal nerve in the posterior fossa. Presented at meeting of New York Academy of Medicine, Feb. 17, 1953.

Walker, A.E. and Nulsen, F.: Electrical stimulation of the upper thoracic portion of the sympathetic chain in man. *Arch. Neurol. & Psychiat.*, *59*:559-560, 1948.

Wallenberg, A.: Die secundare Bahn des sensiblen Trigeminus. *Anat. Anz*, *12*.95-110, 1896.

Wallenberg, A.. Anatomischer Befund in einem als acute Bulbaraffection beschriebenen Falle. *Arch. Psychiat. & Nervenkr.*, *34*.923-959, 1901.

Wallenberg, A.: Anatomischer Befund in einem als Blutung in die rechte Bruckenhalfte etc. aus dem Ramus centralis arteriae radicularis nervi facialis dextri geschilderten Falle. *Deutsches A Nervenh*, *26*.436-464, 1904.

Wallenberg, A.: Verschluss der Arteria cerebelli inferior posterior dextra (mit Sektionsfund). *Deutsche Ztschr. Nervenh.*, *73*:189-212, 1922.

Walshe, F.M R . The anatomy and physiology of cutaneous sensibility: a critical review. *Brain*, *65*:48-112, 1942.

Walton, F.E., Moore, R.M. and Graham, E A : The nerve pathways in the vomiting of peritonitis. *Arch. Surg.*, *12* 829-837, 1931.

Ward, A.A., Jr , and McCulloch, W.S.: The projection of the frontal lobe on the hypothalamus. *J Neurophysiol.*, *10*:309-314, 1947

Wartenberg, R : Klinische Studien zur Frage der Geltung des Bell-Magendieschen Gesetzes. *Z. ges. Neurol Psychiat*, *113*.518-603, 1928.

Waterston, D.: Observations of sensation. The sensory functions of the skin for touch and pain. *J. Physiol*, *77*:251-257, 1933A.

Waterston, D.: On pain. *Lancet*, *224*.943-946, 1933B.

Watts, J.W. and Freeman, W : Psychosurgery for the relief of unbearable pain. *J. Internat. Coll Surgeons*, *9* 679-683, 1946.

Watts, J.W. and Freeman, W.: Frontal lobotomy in the treatment of unbearable pain *Research Publ. A. Nerv. & Ment. Dis.*, *27*:715-722, 1948.

Watts, J.W. and Murphy, J.P. Psychosurgery: Surgical aspects. Chap 21B in *Progress in Neurology and Psychiatry*, edited by E.A. Spiegel, New York, Grune & Stratton, 1949, pp. 395-401

Weaver, T.A.,Jr. and Walker, A.E Topical arrangement within the spinothalamic tract of the monkey *Arch. Neurol & Psychiat.*, *46* 877-883, 1941.

Weddell, G.: The clinical significance of pattern of cutaneous innervation. *Proc. Roy. Soc. Med.*, *34*.776-778, 1941A.

Weddell, G.: The multiple innervation of sensory spots in the skin *J. Anat., London*, *75*:441-446, 1941B.

Weddell, G. and Harpman, J.A : The neurohistological basis for the sensation of pain provoked from deep fascia, tendon and periosteum. *J. Neurol. & Psychiat.*, *3*.319-328, 1940.

Weddell, G., Sinclair, D.C. and Feindel, W H.: An anatomical basis for alterations in quality of pain sensibility. *J. Neurophysiol.*, *11*.99-109, 1948.

Weddell, G., Sinclair, D.C., Feindel, W.H. and Falconer, M A.: The intervertebral ligaments as a source of segmental pain *J. Bone & Joint Surg.*, *30-B*.515-521, 1948.

Weeks, C., Ryan, B J., and Van Hoy, J.M.: Two deaths associated with supradiaphragmatic vagotomy. *J.A.M.A*, *132*.988-990, 1946

Weinberger, L.M. and Grant, F.C : Experiences with intramedullary tractotomy: III. Studies in sensation. *Arch. Neurol. & Psychiat.*, *48*.355-381, 1942

Weisenburg. T.H : Cerebello-pontile tumor diagnosed for six years as tic douloureux: The symptoms of irritation of the ninth and twelfth cranial nerves. *J.A M.A*, *54*:1600-1604, 1910

WOLFF, H.G. and WOLF, S.: *Pain.* Springfield, Illinois, Thomas, 1948, 68 pp.

WOLFSON, W.Q. and GRAHAM, J.R.: Development of tolerance to ergot alkaloids in a patient with unusually severe migraine. *New England J. Med., 241*:296-298, 1949.

WOMACK, N.A. and CRIDER, R.L.: The persistence of symptoms following cholecystectomy. *Ann. Surg., 126*:31-55, 1947.

WOOLLARD, H.H.: The innervation of blood vessels. *Heart, 13*:319-336, 1926.

WOOLLARD, H.H.: Observations on the terminations of cutaneous nerves. *Brain, 58*:352-367, 1935.

WOOLLARD, H.H.: Continuity in nerve fibres. *J. Anat., 71*:480-491, 1937.

WOOLLARD, H.H., ROBERTS, J.E.H. and CARMICHAEL, E.A.: An inquiry into referred pain. *Lancet,* 222:337-338, 1932.

WOOLLARD, H.H., WEDDELL, G. and HARPMAN, J.A.: Observations on the neurohistological basis of cutaneous pain. *J. Anat., 74*:413-440, 1940.

WOOLSEY, C.N.: "Second" somatic receiving areas in the cerebral cortex of cat, dog and monkey. *Federation Proc., 2*:55-56, 1943.

WOOLSEY, C.N. and FAIRMAN, D.: Contralateral, ipsilateral and bilateral representation of cortical reception in somatic areas I and II of the cerebral cortex of pig, sheep and other mammals. *Surgery, 19*:684-702, 1946.

WOOLSEY, C.N., SETTLAGE, P.H., MEYER, D.R., SENCER, W., HAMUY, T.P. and TRAVIS, A.M.: Patterns of localization in precentral and "supplementary" motor areas and their relation to the concept of a premotor area. *Research Publ. A. Nerv. & Ment. Dis., 30*:238-264, 1952.

WORTIS, H., STEIN, M.H. and JOLLIFFE, N.: Fiber dissociation in peripheral neuropathy. *Arch. Int. Med.,* 69:222-237, 1942.

WYBURN-MASON, R.: Significance of the reference of anginal pain to the right or left side of the body. *Am. Heart J., 39*:325-335, 1950.

WYCIS, H.: Bilateral intracranial section of the glossopharyngeal nerve. *Arch. Neurol. Psychiat., 54*:344-347, 1945.

ZENKER, R.: Die Behandlung der Trigeminusneuralgie unter besonderer Berucksichtigung der Grundlagen, der Ausfuhrung und der Ergebnisse der Punktion und Elektrocoagulation des Ganglion Gasseri nach Kirschner. *Ergebn. chir Orthop., 31* 1-82, 1938.

ZOLLINGER, R.: Observations following distension of the gallbladder and common duct in man. *Proc. Soc. Exper. Biol., New York, 30*:1260-1261, 1933.

ZOTTERMAN, Y.: Studies in the peripheral nervous mechanism of pain. *Acta med scandinav., 80*:185-242, 1933.

ZOTTERMAN, Y: Touch, pain and tickling: An electrophysiological investigation on cutaneous sensory nerves. *J. Physiol., 95*:1-28, 1939.

WHITE, J.C., HEROY, W.W. and GOODMAN, E.N.: Causalgia following gunshot injuries of nerves: Role of emotional stimuli and surgical cure through interruption of diencephalic efferent discharge by sympathectomy. *Ann. Surg.*, *128*:161-183, 1948.

WHITE, J.C. and SMITHWICK, R.H.: *The Autonomic Nervous System: Anatomy, Physiology and Surgical Application*. 2nd ed., New York, Macmillan, 1941, 469 pp.

WHITE, J.C., SMITHWICK, R.H. and SIMEONE, F.A.: *The Autonomic Nervous System: Anatomy, Physiology and Surgical Application* 3rd ed., New York, Macmillan, 1952, 569 pp.

WHITE, J.C., SWEET, W H., HAWKINS, R. and NILGES, R.G.: Anterolateral cordotomy: Results, complications and causes of failure. *Brain*, *73*:346-367, 1950.

WHITE, J.C., VERLOT, M.G. and EHRENTHEIL, O.: Neurogenic disturbances of the colon and their investigation by the colonmetrogram: A preliminary report. *Ann. Surg.*, *112*:1042-1057, 1940.

WHITE, J C. and WHITE, P.D.: Angina pectoris: Treatment with paravertebral alcohol injections. *J.A.M.A.*, *90*.1099-1103, 1928.

WHITELAW, G.P. and SMITHWICK, R H.: Some secondary effects of sympathectomy, with particular reference to disturbance of sexual function. *New England J. Med.*, *245*.121-130, 1951.

WIENER, N.: *Cybernetics* New York, John Wiley & Sons, Inc, 1948, 194 pp.

WILKINS, H.· The transdural approach to posterior rhizotomy for trigeminal neuralgia. Presented at meeting of Society of Neurological Surgeons, Omaha, Nebraska, June 12, 1948

WILLIAMS, J.M. and FREEMAN, W.: Transorbital lobotomy in the relief of intractable pain *Arch Surg.*, *63*:203-210, 1951.

WILSON, A.A.: Geniculate neuralgia: Report of a case relieved by intracranial section of the nerve of Wrisberg. *J Neurosurg.*, *7*.473-481, 1950.

WILSON, G. and FAY, T.: Two cases of chordotomy, indicating the distinct separation of pain and temperature fibers in the anterolateral aspect of the spinal cord, as well as the relative position of these fibers supplying the trunk and lower extremity. *Arch Neurol. & Psychiat.*, *22*.638-641, 1929.

WILSON, G. and WINKELMAN, N.W.: Occlusion of the posterior inferior cerebellar artery. *J. Nerv. & Ment. Dis.*, *65*:125-30, 1927

WILSON, J.G.: The nerves and nerve endings in the membrana tympani of man. *Am. J. Anat.*, *11*:101-112, 1911.

WILSON, R B. and MUSSEY, R.D · Nervous pathways involved in pelvic pain: Some anatomic and physiologic aspects *J.A M.A*, *134*.857-861, 1947.

WILSON, S A.K.. A case of thrombosis of the left posterior inferior cerebellar artery. *Proc. Roy. Soc. Med.*, *2*:52-76, 1909.

WINDLE, W F.: Neurons of the sensory type in the ventral roots of man and of other mammals. *Arch. Neurol. Psychiat*, *26*.791-800, 1931.

WINKLER, C.: *Manuel de neurologie* Haarlem, de Erven F. Bohn, 1921, Vol. I, Pt. 2, L'appareil nerveux du nervus trigeminus et celui du nervus octavus.

WINTHER, K.: Tractotomy (Sjoqvist), viewed in the light of the pathology of the medulla oblongata. *Acta psychiat, Kbh.*, *14*.243-248, 1939.

WOHLWILL, F.: Zur pathologischen Anatomie des Nervensystems vom Herpes zoster. *Z. ges Neurol. Psychiat*, *89*:170-212, 1924.

WOLF, S. and WOLFF, H.G.: *Human Gastric Function: An Experimental Study of a Man and His Stomach*. New York, Oxford University Press, 1943, 195 pp.

WOLF, S, WOLFF, H G and GOODELL, H.: Unpublished observations quoted in paper by H G. WOLFF and J D HARDY, On the nature of pain. *Physiol. Rev*, *27*:167-199, 1947.

WOLFERTH, C.C., CHAMBERLAIN, R.H. and MEAD, J J: Radioactive iodine in the treatment of angina pectoris. *Penn. Med. J.*, *54*.352-358, 1951

WOLFF, H G.: *Headache and Other Head Pain* New York, Oxford University Press, 1948, 642 pp.

WOLFF, H.G. and HARDY, J.D.: On the nature of pain. *Physiol. Rev*, *27*:167-199, 1947.

WOLFF, H.G., HARDY, J D. and GOODELL, H.: Experimental studies on the nature of hyperalgesia. *Arch. Neurol. & Psychiat*, *63* 188-189, 1950

AUTHOR INDEX

SUBJECT INDEX

THIS BOOK

PAIN

ITS MECHANISMS AND NEUROSURGICAL CONTROL

By James C. White, M.D., F.A.C.S.

and

William H. Sweet, M.D., F.A.C.S.

was set, printed and bound by The E. W. Stephens Publishing Company of Columbia, Missouri. The engravings were made by The Capitol Engraving Company of Springfield, Illinois. The page trim size is 7 x 10 inches. The type page is 30 x 48 picas. The type face is Caledonia, set 11 point on 13 point. The text paper is 70-pound Cumberland Gloss. The cover is Bancroft's Buckram 5390.



THIS BOOK

PAIN
ITS MECHANISMS AND NEUROSURGICAL CONTROL

By JAMES C. WHITE, M.D., F.A.C.S.

and

WILLIAM H. SWEET, M.D., F.A.C.S.

was set, printed and bound by The E. W. Stephens Publishing Company of Columbia, Missouri. The engravings were made by The Capitol Engraving Company of Springfield, Illinois. The page trim size is 7 x 10 inches. The type page is 30 x 48 picas. The type face is Caledonia, set 11 point on 13 point. The text paper is 70-pound Cumberland Gloss. The cover is Bancroft's Buckram 5390.

